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THE UNIVERSITY OF ALBERTA

ASSESSMENT OF THE NUTRITIVE VALUE OF LOW GLUCOSINOLATE, LOW ERUCIC ACID RAPESEED MEAL AS A SOURCE OF PROTEIN FOR PIGS AND RATS

by

© PHILIP JOHN McKINNON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

IN

Animal Nutrition

DEPARTMENT OF ANIMAL SCIENCE

EDMONTON, ALBERTA

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THE UNIVERSITY OF ALBERTA

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Assessment of the nutritive value of low glucosinolate, low erucic acid rapeseed meal as a source of protein for pigs and rats" submitted by Philip John McKinnon, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Animal Nutrition.

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ABSTRACT

Studies were undertaken to assess the nutritive value of low glucosinolate, low erucic acid rapeseed meal (00-RSM), cultivar Tower, as a source of protein for pigs and rats compared with commercially available rapeseed meal (C-RSM) and soybean meal (SBM). Studies were also made to determine the effects of these protein sources on thyroid hormone function in pigs and rats.

A total of 80 pigs in one experiment and 33 pigs in another experiment as well as 50 rats were used in these studies. Treatments consisted of feeding isonitrogenous diets containing SBM, 00-RSM or C-RSM as complete replacement for SBM or isonitrogenous combinations of SBM with either source of RSM. Diets were also isocaloric.

During the starting phase from 4 to 10 weeks of age, pigs fed the 00-RSM diets consumed more feed ($P<.05$), gained faster ($P<.05$) and converted feed to body weight gain more efficiently ($P<.05$) than pigs fed the C-RSM diet but consumption of these two diets was not significantly different. Feed consumption was less ($P<.05$) for pigs fed 00-RSM than those fed SBM pigs fed 00-RSM diets. Partial replacement of SBM with 00-RSM resulted in performance similar to pigs fed SBM while partial replacement of SBM by

C-RSM resulted in performance similar to pigs fed 00-RSM diets.

During the growing and finishing phases feed consumption was not significantly different for any diet. Gain and efficiency of feed conversion were less ($P<.05$) for pigs fed 00-RSM compared with SBM in the growing period although the latter parameter was not significantly different in the finishing period. These parameters were markedly depressed for pigs fed C-RSM compared with all other diets.

Feed consumption, gain and feed conversion of rats fed 00-RSM diets was significantly ($P<.05$) lower than rats fed SBM. Performance was depressed in rats fed both diets containing C-RSM.

Digestibility of energy, nitrogen and amino acids of both pigs and rats fed 00-RSM and C-RSM diets was depressed compared with animals fed SBM but these differences were not consistently significant. Digestibility of diets in which SBM was partially replaced by either source of RSM was intermediate compared with those containing only SBM or RSM.

Thyroid weight expressed as a function of body weight was greater ($P<.05$) and thyroxine levels of blood serum were reduced ($P<.05$) for pigs fed both diets containing C-RSM compared with pigs fed other diets except thyroxine levels

of pigs fed 00-RSM were significantly lower in one case than pigs fed the SBM diet. Serum cholesterol and glucose were elevated ($P<.05$) and alkaline phosphatase was depressed ($P<.05$) in pigs fed the C-RSM diets. These findings are indicative of a possible hypothyroid condition in pigs fed high levels of C-RSM in these experiments. Thyroid function of pigs fed high levels of 00-RSM was similar to pigs fed the SBM diets.

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INTRODUCTION

Production of rapeseed (RS) is of very ancient origin and recorded usage is known from early Sanskrit writings of 2000-1500 B.C. (Downey, 1965). China and India still account for the majority of the total world production of RS (Armstrong, 1975). The first commercial production of RS in Canada was in 1943 when Argentine-type RS (Brassica napus) was grown initially at the request of the Canadian government for production of oil for marine and aircraft engine lubricants. Prior to 1943, small amounts of rape of Polish type (Brassica campestris0 were grown in the Shellbrook area of Saskatchewan. Since these modest beginnings, acreage devoted to production of RS has expanded to 3,950,000 acres (1,598,000 hectares) (Statistics Canada, 1976) in 1975 and rapeseed is now the third major cash crop in the Western Canadian prairie provinces.

Rape is a member of the Cruciferae family and two summer species are commonly grown in Canada: Brassica campestris L. commonly called Polish rape or turnip rape and Brassica napus L. commonly called Argentine rape. Although B. napus was initially the major species grown, the shorter growing period, greater drought resistance and shattering resistance of the pods during harvesting of B. campestris has proven to be of benefit in more northern areas where the bulk of RS production is concentrated. At

the present time greater acreage is devoted to B. campestris than to B. napus although B. napus produces a greater yield of seed and is resistant to staghead, a white rust which is a major disease problem in areas of B. campestris production (Downey et al, 1975).

Production of RS is dependent largely upon demand for oil and meal which governs the price of RS, as well as price ratios between wheat, coarse grains and RS. These cereal crops compete for the same acreage as RS (Runciman and Olsen, 1975) and within certain limits relative prices dictate the crops which will be grown on a given area of land. Historically, rape has been an emergency crop, often grown in a year when early crops failed or seeding was delayed.

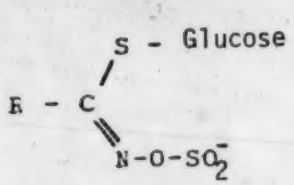
RS is grown largely for the oil content (40%) which is utilized mainly as an edible oil in margarine and cooking oil (Runciman and Olsen, 1975). The resulting meal, which is a by-product of oil extraction, contains a high level of protein (36%, on an air dry basis) of good biological value (Bowland, 1965). The amino acid pattern of rapeseed meal (RSM) is quite similar to that of soybean meal (SBM) but RSM contains a higher level of methionine and slightly less lysine than SBM (Clandinin et al, 1972). Therefore, RSM is a potential partial substitute for SBM in livestock and poultry diets. Currently, a level of 5% rapeseed meal (RSM)

is recommended in the diets of starting, growing and finishing pigs and up to 10% RSM may be used where a favourable price ratio exists in favour of RSM compared with other protein sources (Bowland and Bell, 1972).

The recommendations restricting the use of RSM in pig diets have been formulated as a result of the potential toxicity for pigs of certain compounds, called glucosinolates, which appear to be present in all species of Cruciferae (Ettlinger and Kjaer, 1968). Glucosinolates have been implicated as the likely cause of depression in performance and inhibition of normal thyroid metabolism when RSM is fed to pigs (Bowland, 1965).

Glucosinolates are anions with the general structural formula as shown in Figure 1. Ettlinger and Lundeen (1956) characterized the breakdown of glucosinolates by an enzyme system, myrosinase (thioglucoside glucohydrolase, E.C. 3.2.3.1.) yielding glucose, sulfate ion and an isothiocyanate or products formed by isothiocyanate reactions.

Figure 1. General formula of glucosinolates



As a result of the problems associated with using RSM as a source of protein in livestock diets, a great deal of research has been conducted to develop varieties of RS, such as the cultivar Tower, which have low levels of both glucosinolates and erucic acid, a 22-carbon fatty acid which has been linked tc undesirable cardiac alterations when the oil supplied a large part of the energy of the diet in male rats and pigs (Roine et al, 1960; Beare-Rogers and Nera, 1972). Beare-Rogers et al (1974) suggested that certain deleterious effects of RS oil on a long-term basis may cause undesirable changes when RS oil is consumed by man. Recently Aherne et al (1975), Friend et al (1975) and Aherne et al (1976) have shown that no significant histological differences were evident in the hearts of pigs fed diets containing high cr low erucic acid RS oil provided protein levels were increased to maintain constant daily protein intake across all diets. This adjustment is required to allow for the decrease in feed intake which occurs in monogastric animals when diets containing large amounts of oil, and which thus have high energy levels, are fed. However, since RSM is defatted and usually only 2-3% residual oil remains in the meal following extraction (Clandinin et al, 1972) it is not likely that erucic acid is of any significance in relation to use of RSM in livestock diets, and erucic acid is, therefore, not considered further in this report.

LITERATURE REVIEW

Effects of Glucosinolates

The glucosinolates present in RS have been known as potent goitrogens for more than 100 years (Greer, 1962; Bell and Belzile, 1965). A review of the metabolism of the thyroid and the effects of glucosinolates is appropriate, particularly since Paddock (1971) suggested that glucosinolates were a major factor hindering increased usage of RSM. In addition, the nutritive value of RSM as a source of protein for pigs and the implications of low glucosinolate RSM will be considered in this review.

Thyroid metabolism

The thyroid in the pig is a concave globular structure located immediately ventral to the trachea at the level of the thoracic inlet and just anterio-dorsal to the anterior vena cava (Dunne, 1970). Unlike most mammals including man, in the pig the thyroid is not a bilobed structure. The gland is well supplied with blood from the carotid artery and drains into the internal jugular vein.

Histologically, the cells of the thyroid are arranged in follicles which have an internal dense staining colloid material (Bell et al, 1968). This proteinaceous colloid is termed thyroglobulin and is believed to be the site of organic iodination of thyroid hormones as well as the main

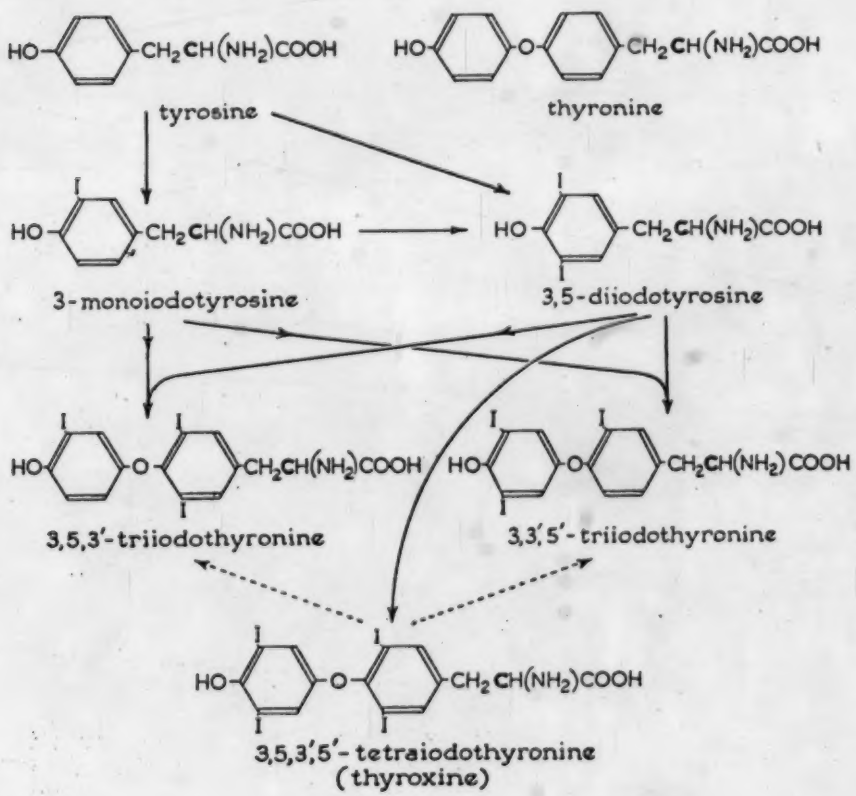
reservoir of organically bound iodine in the thyroid (Harper, 1971). Secretion of the active hormones is accomplished by enzymatic hydrolysis of the peptide bonds by which these hormones are bound within the thyroglobulin molecule (Gharib and Hurd, 1973).

The primary function of the thyroid gland is to produce the thyroid hormones. The two thyroid hormones having greatest physiological activity are 3,5,3'-triiodothyronine (T-3) and 3,5,3',5'-tetraiodothyronine (T-4) (Pitt-Rivers and Rall, 1961). Oppenheimer (1968) and Robbins and Rall (1967) showed that 90% of the organically bound iodine in the blood was accounted for by T-4. T-3 is considered to have four times the calorigenic activity of T-4 while using only 75% as much organically bound iodine which may be of importance in iodine deficiency states (Greer et al, 1968). Also, Chopra et al (1971) have suggested that due to a shorter serum half life of T-3 of 1.0 days vs 6-7 days for T-4, and an estimated daily production of approximately 26 ug of T-3 vs 80 ug/day for T-4, that T-3 may account for two-thirds of the total thyroid hormone effect in humans. Further, Chopra et al (1971) have suggested that more than 30% of the daily production of T-4 is converted to T-3 in the body outside the thyroid, further strengthening the argument that the main functional thyroid hormone is indeed T-3. Mono-iodotyrosine and diiodotyrosine are also produced

by the thyroid as precursor compounds of T-3 and T-4.

Biosynthesis of thyroid hormones is presented in Fig. 2. The basic mechanism involves iodination of tyrosine molecules in the 3-position forming monoiodotyrosine or in the 3,5-positions forming diodotyrosine. These structures are then coupled to form T-3 and/or T-4, (Harper, 1971).

Figure 2. Synthesis of thyroid hormones



The specific effects of thyroid hormones still remain somewhat unclear despite the well known effects of increasing basal metabolic rate (Lehninger, 1970). A

background level of thyroid hormones appears necessary for many functions of the body but much confusion has arisen as a result of administering unphysiologically high doses under experimental conditions. At physiologic concentrations, thyroid hormones appear to stimulate lipid and carbohydrate metabolism, largely through effects on synthesis of adenyl cyclase as related to glycogen and lipid metabolism (Harper, 1971). In addition, an anabolic effect has been suggested by increasing RNA synthesis as well as augmenting protein synthesis by stimulating translation of messenger RNA. Production of growth hormone is also reported to be stimulated by thyroid hormones (Harper, 1971).

Glucosinolate involvement in thyroid metabolism

Deficiency of iodine was shown by early workers to be the primary problem causing thyroid dysfunction resulting in goitre (Coindet, 1820, cited by Greer, 1962). However, it was discovered that ingestion of certain plants, notably cabbage as well as other Cruciferae also produced goitre, even in the presence of sufficient dietary iodine (Chesney et al, 1928, Hercus and Purves, 1936, both cited by Greer, 1962). More recent work (Josefsson, 1970) has shown that many glucosinolates occur in Cruciferae. In rape, the major glucosinolates have been suggested by Bell and Belzile (1965) to be 3-butenyl glucosinolate (gluconapin), 4-pentenyl-glucosinolate (glucobrassiconapin) and 2-hydroxy-3-

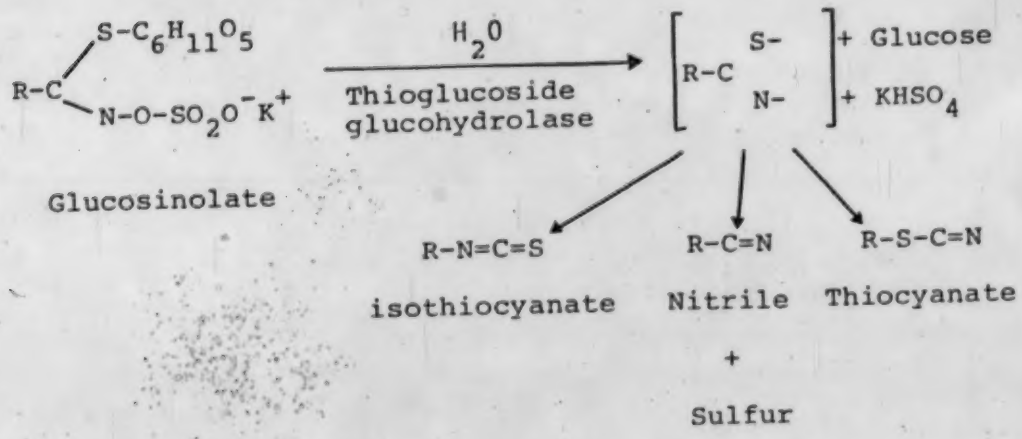
butenyl-glucosinolate (progoitrin). Direct quantification of glucosinolates is very difficult, consequently levels of these compounds are determined on the basis of identification of end products produced by enzymatic hydrolysis of the glucosinolates. Hydrolysis is accomplished by myrosinase, a thioglucosidase, which is a naturally occurring enzyme present in RS and which acts by hydrolysis of the S-glycosyl bond of the glucosinolate. The commonly accepted structure and scheme of hydrolysis of glucosinolates was elucidated by Ettlinger and Lundeen (1956) as in Figure 3.

The structure of the R-group is characteristic of the different glucosinclates. In the case of progoitrin, where a hydroxyl is present in the R-group, a cyclization of unstable isothiocyanate takes place, producing 5-vinyl oxazolidinethionine (OZT) (Bell and Belzile, 1965).

Clandinin et al (1959) found that heat in certain circumstances increased the goitrogenicity of RSM by converting isothyocyanate (ITC) to OZT. Lo and Bell (1972) found that OZT was more toxic for rats than ITC as indicated by growth depression and ^{125}I uptake.

Nitrile formation may also occur with the HSO^- ion eliminated in the initial reaction. Also, the simultaneous occurrence of a nitrile and an ITC is known (Bell and

Figure 3. The general structures of glucosinolates and products formed by enzymatic hydrolysis, followed by chemical rearrangement reactions



Belzile, 1965). Daxenbichler (1967) et al suggested that pH and conditions of hydrolysis of progoitrin could influence the hydrolytic products formed. In situations involving low pH or autolysis of glucosinolates by the native thioglucosidase at rocm temperature, considerable quantities of nitriles were formed frcm progoitrinn (Van Etten et al, 1966). Tookey et al (1965) and Van Etten et al (1969) found such nitriles to be more toxic for rats than OZT considering growth, thyroid weight and histology as well as other tissue pathology. This finding has been confirmed by Lo and Hill (1972) and more recently by Josefsson (1975) using mice.

The implication of these findings is that in unheated

RSM, nitriles can be formed by the native thyioglucosidase (myrosinase) in the meal under the low pH conditions of the stomach of monogastric animals and that hydrolysis of these compounds occurs in less than 4 hours (Lo and Hill, 1972). However, in the case of heated RSM in which the native glucosidase was inactivated, Lo and Hill (1972) found that OZT was formed and was released to the animal from the gut at a lower concentration over a longer period of time (16-36 hours) than in unheated meals. Previous work by Lo and Hill (1971a) had shown that during incubation of tissue from numerous organs, no glucosinolate products were formed, indicating that a thioglucosidase was not present in the tissue. The implication of this finding is that the enzymes necessary to hydrolyze dietary glucosinolates must come from outside the animal body. It has long been believed that the bacteria normally present in the intestines can hydrolyze glucosinolates. Recently, Marangos and Hill (1974) directly demonstrated the presence of myrosinase in caecal contents of chickens and also in the contents of the ilium and colon in caecectomized birds, but not in the caecal wall. The enzyme activity could be inhibited by neomycin. This direct demonstration of the enzyme in normal gut microflora, together with the previous work, clearly shows the involvement of gut bacteria in metabolism of glucosinolates in the animal. This also raises a host of ramifications regarding glucosinolate metabolism in relation to dietary

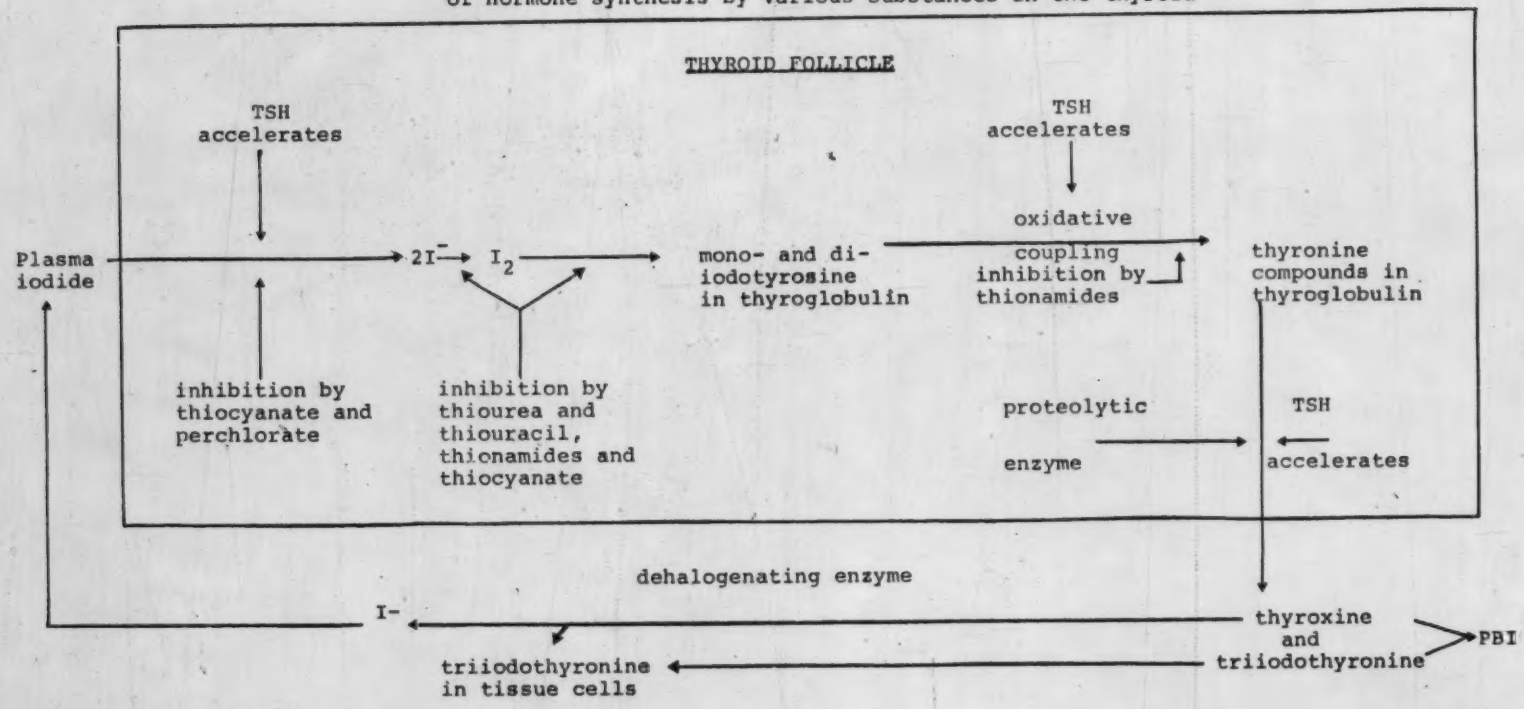
administration of antibiotics, resistance of the gut micro-organisms to these antibiotics and composition of the bacterial population. It is possible that such factors could account for some of the variability of animal response to RSM in the diet observed under both experimental and practical conditions.

Glucosinolate effects on thyroid function

The inhibitory effects of glucosinolates on thyroid function can occur in several sites within the thyroid depending on the type of hydrolytic product which is involved (Figure 4). Thiocyanates (TC), including ITC, may act in two ways: by inhibiting the uptake of iodide from the plasma by the thyroid and by inhibiting the organic iodination of tyrosine molecules in thyroglobulin (Greer et al, 1966; Green, 1971). Administration of high levels of iodine appear to partially protect the thyroid from the effects of thiocyanate and presumably ITC. Greer (1962) explained the protective effect of high levels of iodine in terms of mass action effect on competitive uptake of TC or iodide by the thyroid.

The main effects of thionamides, such as OZT, on the thyroid stems largely from an inhibition of the coupling of tyrosine residues to form thyronine (Greer et al, 1964; Green, 1971).

Figure 4. Scheme of metabolism of thyroid hormones and sites of inhibition of hormone synthesis by various substances in the thyroid



(adapted from Bell et al, 1968)

Thionamides also inhibit iodination of tyrosine (Richards and Ingebar, 1959) but iodine transport does not appear to be affected (Green, 1971; Lo and Hill, 1971b). The exact mechanisms of thionamide action on the thyroid are not clearly understood, but administration of iodine does not appear to be beneficial in terms of hormone production but may partly inhibit goitre formation in rats (Taylor and Barrett, 1965). Finnish researchers found enlargement of thyroids even when excess iodine was administered to rats consuming small amounts (0.5 ug/day) of OZT in water (Krusius and Peltola, 1966).

It is apparent that the goitrogens in RSM can cause a disturbance in thyroid metabolism. The effects of these compounds may result in two types of goitrous conditions which have important implications in regard to utilization of RSM;

a) compensated goitre: thyroid enlarges in response to stimulus of thyroid stimulating hormone (TSH) via the hypothalamic-pituitary feedback mechanism, i.e., goitrogen decreases effective thyroid hormone secretion and plasma hormone levels decrease. A hypothalamic-pituitary response to low circulating thyroid hormones results in increased secretion of TSH. Enlargement of the gland under stimulus of TSH permits normal (euthyroid) plasma T-3 and T-4 levels and normal or near normal growth occurs.

b) uncompensated goitre: thyroid enlarges as above but euthyroid T-3 and T-4 levels cannot be maintained. The classical hypothyroid condition then occurs.

Nutritional Implications of Low Glucosinolate Rapeseed Meal

Removal of glucosinolates or lowering of the content of these compounds in RS to metabolically insignificant levels for the animal consuming RSM should remove the majority of the inhibitory effects on growth observed when RSM is fed to monogastric animals, particularly pigs (Bowland, 1965). A low level of glucosinolate should thus markedly increase nutritive value of RSM and lead to recognition of RSM as a good source of supplemental protein in the diet of pigs.

Recent rape breeding work in Canada and elsewhere has resulted in the identification of a variety of B. napus from Poland, Bronowski, which has a lower level of glucosinolates than other varieties of rape (Kondra and Stefansson, 1970; Appelquist, 1972; Finlayson et al, 1973). Although this cultivar is not well suited to Canadian conditions, it has served as a valuable source of genetic material for improved low-glucosinolate, low-erucic acid cultivars, such as Tower, which also have improved agronomic characteristics (Downey et al, (1975).

Although little information is available on the nutritive value of low glucosinolate, low-erucic acid meals,

a considerable number of recent publications on the nutritive value of Bronowski RSM are now available. A review of this information is of value since Bronowski is the most likely source of low-glucosinolate genes in rape in the near future (Downey et al, 1975). The available information on the nutritive value of Tower RSM (00-RSM) will be included in this review.

Genetic crosses of Bronowski with other RS cultivars containing average amounts of glucosinolates indicate that the glucosinolate content is greater than Bronowski but considerably less than the other high glucosinolate parent (Downey et al, 1975). Wetter (1965) determined glucosinolate levels in B. campestris and B. napus from Canadian sources and found variation in the levels of both species: ITC-4.4-7.2 (mean 5.4); OZT-0.9-2.1 (mean 1.2) mg/g for B. campestris and ITC-3.0-4.6 (mean 3.6); OZT-3.0-5.4 (mean 4.6) for B. napus. Both Wetter (1965) and Clandinin et al, (1959) report that B. campestris had lower levels of OZT than B. napus. Appelquist (1972) has published an extensive listing of the glucosinolate contents of European winter and summer cultivars of both species of rape. Values for total glucosinolate content expressed as gluconapin and progoitrin ranged from 4.3-7.8 mg/g (mean 5.7) of dry matter in the meal. B. campestris values ranged from 3.3-4.3 (mean 3.6) mg/g and Bronowski ranged from 0.2-3.6 (mean 1.5)

mg/g. The values for Bronowski are clearly less than medium glucosinolate varieties reported by Wetter (1965). These values have been confirmed by Josefsson (1975) who found lower levels than the mean values quoted above. These reports effectively demonstrate the decrease in glucosinolate content of RS due to advances in rape breeding.

Bell et al, (1972) determined the major glucosinolates in RSM from a number of cultivars of rape including Bronowski (Table 1). The inclusion in this study of several species of rape gave a range of levels of OZT plus ITC and the effects of these genetically determined combinations of glucosinolates were evaluated by considering growth rate and thyroid histology of rats and mice.

It is evident in Table 1 that Browowski contained very low levels of glucosinclates while Oriental mustard or Yellow Sarson (a *B. campestris* cultivar) contained high levels of ITC but no OZT. Target (*B. napus*) contained high levels of OZT. Nitriles were produced by treating Target with ferrous sulfate. No significant differences on body weight gain, feed intake (FI) or feed conversion efficiency (FCE) were observed when either Bronowski or casein was used as a protein source in the diets of rats or mice. Growth rate and histopathology of the thyroid gland were affected by the inclusion of the rapeseed meals other than Bronowski,

Table 1. Content of glucosinolate products in rapeseed meals with and without myrosinase

Rapeseed meal	Myrosinase	Glucosinolate products (mg aglycone/g oil-free dry meal)				
		Allyl isothio-cyanate	Butenyl isothio-cyanate	Pentenyl isothio-cyanate	Oxazo-lidinethione	Hydroxy-nitrile
Bronowski	+	—	0.07	—	0.6	—
	−	—	—	—	—	—
Oriental mustard	+	5.3	—	—	—	—
	−	—	—	—	—	—
Yellow Sarson	+	—	10.5	—	—	—
	−	—	—	—	—	—
Target	+	—	2.8	0.9	10.6	—
	−	—	—	—	—	—
Fe-treated Target	+	—	1.8	0.4	5.7	1.9
	−	—	—	—	—	2.3

(Bell et al., 1972)

but effects were much more pronounced with diets containing high glucosinolate RSM (Target).

Essentially the same findings were reported by Lo and Hill (1971b) for the growth promoting effects of Bronowski RSM but thyroid weights were significantly ($P<.05$) greater than controls fed casein. Also ^{125}I uptake was more rapid in thyroids of rats fed Bronowski meal and release rate of ^{125}I as thyroid hormone was slower than rats fed control diets. Rats fed high glucosinolate B. napus RSM showed ^{125}I metabolism patterns similar to controls but at a reduced rate. Later studies by Lo and Bell (1972) with RSM, but not including Bronowski showed that growth of rats was depressed and ^{125}I uptake and release was also depressed by high glucosinolate B. napus RSM. The results suggested that RSM inhibited iodine uptake; organic iodination and coupling of tyrosine residues. Since RSM contains both OZT, which is a thionamide, as well as thiocyanate, these results can be attributed to the previously outlined effects of both OZT and ITC. Interpretation of the growth data in the report of Lo and Bell (1972) is difficult since the diets do not appear to be either isocaloric or isonitrogenous. The apparent confounding of the nutritional aspects of this trial should not, however, affect the validity of the results of thyroid inhibition by RSM. Earlier work had indirectly demonstrated similar thyroid inhibition by the

glucosinolates present in RSM (reviewed by Bell and Belzile, 1965).

The goitrogenic effect of Brcnowski demonstrated by Lo and Hill (1971b, 1972) is not unexpected since the majority of the glucosinclates present in RSM of B. napus origin is progoitrin (Van Etten et al, 1966; Bell et al, 1972). This compound is known to be a more potent goitrcgen than the isothiocyanate gluccsinclates (Bell and Belzile, 1965; Tookey et al, 1965) primarily as a result of inhibiting the tyrosine coupling reaction as well as inhibiting iodination of tyrosine (Green, 1971). As was previously mentioned, Krusius and Peltola (1966) demonstrated that chrcnic administration of as little as 0.5 ug/day of purified OZT, i.e., the hydrclytic product of progoitrin, caused thyroid enlargement in rats. As part of the same experiment, single doses were orally administered as opposed to continuous dosage. It was demcnstrated that 0.1-0.5 mg OZT per animal was required to show a significant effect ($P<.01$) of one oral dose of OZT on thyroid function as evidenced by uptake of ^{131}I.

It is of interest to compare the levels of intake of glucosinolates in the work of Krusius and Peltola with other reports. Using the values for glucosinolate content and feed intake given by Lo and Hill (1971b), and assuming the values given for gluccsinolate content of their diets are in

mg/g of diet and not percent as stated, the daily glucosinolate intake of the rats used by Lo and Hill can be calculated. The glucosinolate content of the Bronowski diet was 0.3 mg/g and FI was 222.4 g for 21 days. The daily intake of glucosinclates of rats fed the Bronowski diet was then 3.2 mg/day. For rats fed a RSM diet containing commercially available B. napus and consuming 76.8 g of a diet with a glucosinclate content of 2.6 mg/g, the glucosinolate intake would have been 9.5 mg/day. Lo and Bell (1972) found that hydrolytic products of glucosinolates had almost 2.5 times the potency of the glucosinolates in RSM, therefore, the above values would have to be reduced to approximately 1.3 mg and 3.8 mg/day for Bronowski and commercial B. napus diets to make even a very rough comparison with the values of Krusius and Peltola (1966). This work does indicate, however, that considerable amounts of goitrogen were being consumed by the animals even on Bronowski RSM. These levels of goitrogen may be sufficient to cause thyroid enlargement and inhibition of thyroid function when consumed on a chronic basis as evidenced by the work of Krusius and Peltola (1966). The difference in daily glucosinolate intake could perhaps explain the difference in 21-day gain of 95.3 g for Bronowski-fed rats and 9.5 gm for commercial B. napus.

Josefsson and Munk (1973) investigated the shape of

dose-response curve of glucosinclates in RSM in mice by using segregating F-2 lines from crosses of Bronowski and a high glucosinolate rape to produce different glucosinolate levels. Weight gain, feed intake and protein efficiency ratio showed virtually a linear dose-response relationship between 1 and 3 mg ITC + OZT/g of diet with a correlation coefficient (r) of 0.85, 0.78 and 0.81 between ITC + OZT levels and gain, FI or protein efficiency ratio, respectively. No effect on these parameters was noted when diets contained less than 1 mg/g of diet. Josefsson (1975) evaluated the growth inhibiting effects of unheated, low-glucosinolate (0.9 gm/g) Bronowski RSM in mice. Growth of mice was markedly depressed on Bronowski RSM in which autolysis of the glucosinolates by the native thioglucosidase system occurred, compared with properly heated RSM or meal in which autolysed glucosinolates had been removed with methylene chloride. Growth of mice fed heated Bronowski RSM was similar to casein-fed controls. Nitriles were identified in extracts of autolysed meals but OZT and ITC were not present. The toxicity of nitriles in the amounts which could theoretically be produced from Bronowski RSM was shown directly to account for the growth depression observed. This work explains the previous findings of Josefsson (1974) that growth of mice fed diets containing unheated Bronowski RSM was inferior to animals fed heated meal. This work is supported by the findings of

Tookey et al (1965) and Van Etten et al (1969) who demonstrated that such nitriles were much more toxic than OZT or ITC. The results suggested that the growth-inhibiting effect of unheated, low-glucosinolate RSM was mainly due to the presence of factors, suggested to be enzymes, that direct the autolysis of glucosinolates toward nitrile production (Josefsson, 1975). It may be of particular relevance, considering the above findings by Josefsson (1975), that in the animal, hydrolysis in the stomach occurs in very acid pH conditions and at body temperature, conditions which Van Etten (1969) found were conducive to nitrile formation when autolysis of RSM occurred. Lo and Bell (1971) showed that OZT and ITC were the main products of hydrolysis of glucosinolates in heated meals and that those products were released slowly over a period of several hours resulting in a lower glucosinolate "load" to the animal than from unheated RSM. Recently Marangos and Hill (1974) demonstrated that myrosinase activity occurs in gut microflora thereby elucidating the method of hydrolysis of glucosinolates in heated meal where the native myrosinase had been inactivated.

The important implication of the toxicity of unheated low-glucosinolate RSM is that such toxicity is due to nitrile production. Large amounts of unheated low-glucosinolate rapeseed should not therefore, be fed to non-

ruminant animals. Also, volunteer rape even of low-glucosinolate cultivars may continue to be a problem in swine nutrition.

Rapeseed Meal as a Source of Protein for Pigs

Monogastric animals such as swine require a dietary source of protein sufficient to meet their essential amino acid requirements. Quantitatively it is necessary to supply sufficient amino acids to meet the genetic potential of the animal to synthesize protein as well as to meet requirements qualitatively in terms of amino acid availability. In Canada the main source of protein for swine is SBM, however, a great deal of research has been conducted to determine the value of RSM in pig diets. The primary interest is economic as RS can be extensively grown in Western Canada, whereas soybeans cannot.

Recent publications (Clandinin et al, 1972) on RSM and SBM from Canadian sources indicates that the amino acid pattern of RSM is similar to SBM when calculated as a percent of the protein. Crude protein (CP) levels of RSM are 35-37% vs 45% for SBM with hulls (Clandinin et al, 1972) or 48.5-50% for dehulled SBM (NAS-NRC, 1973). Because of the difference in prctein levels, amino acids in RSM on an "as fed" basis are lower than in SBM.

RSM for young pigs

The young pig requires a highly nutritious readily acceptable diet of at least 18% CP (Meade et al, 1965) and 3500 kcal of digestible energy (DE)/kg for maximum performance (NAS-NRC, 1973), although O'Grady and Bowland (1972) obtained satisfactory performance with 3.2 to 3.4 Mcal/kg in 18% CP diets. The young pig must contend with the shock of weaning which usually results in a growth depression for 7-10 days (Smith and Lucas, 1956; Okai and Aherne, 1976). Although little information is available on use of RSM for very young pigs, Hussar and Bowland (1959a) did not find any depression of feed intake from use of RSM in the diet if 3 week old pigs were not given a choice of diets. However, pigs of this age consumed less of a RSM-based diet compared with SBM if given a choice of diets containing RSM at levels from 0 to 10% of the diet. In more recent studies Manns and Bowland (1963), using pigs of 9-23 kg observed that when all of the SBM was replaced on an isonitrogenous basis by solvent extracted B. campestris RSM in diets with 17% CP, average daily gain (ADG), FI, and FCE were significantly ($P<.05$) depressed. A recent report by Bowland (1974a) using 11.5% Bronowski RSM in diets as a complete replacement for SBM has not shown any depressing effect on growth parameters for barrows from 6 to 12 weeks of age but ADG, FI and FCE were significantly ($P<.01$)

depressed for gilts. There were no differences between sexes in digestibility which would account for the effects in gilts. In another study, Bowland (1974b) found that pigs fed the "accepts" fraction of air-classified RSM as a partial or complete replacement for SBM grew more slowly and consumed less feed from 3-14 weeks of age than pigs fed SBM. Work by Bowland (1975) using 19.5-22% 00-RSM as a complete replacement for SBM in starter grower diets has not shown any significant depression in performance of young pigs. Bowland et al (1975) also fed 00-RSM in partial replacement for SBM or faba beans as a protein supplement atlevels of 3.7-14.5% of the diet and did not find any depressing effects of 00-RSM on performance.

" RSM for growing and finishing pigs

Hussar and Bowland (1959a) found that less than 10% RSM of B. napus origin did not depress performance of growing-finishing pigs but at a 10% level, reduced rate of growth and inferior FCE in pigs was noted. Manns and Bowland (1963) reported significant ($P<.05$) reductions of ADG, FI and inferior FCE from 23-50 kg liveweight when 50% or 100% of the supplemental protein came from B. campestris type of RSM. Addition of 0.2% L-lysine to diets containing 100% RSM as a protein supplement was without any significant effect on performance. The 100% RSM supplementation provided 15.6% and 9.6% of the total diet derived from RSM for growing and

finishing diets, respectively. The RSM used in the studies in the above report were high glucosinolate varieties.

Omole and Bowland (1974a) found no significant differences in ADG, FI, FCE or digestion coefficients in diets containing 14.5% protein level from either RSM or SBM from weaning to market. Similar results were found in a second experiment using Bronowski RSM (Omole and Bowland, 1974b). It is interesting to note that in the above work which was designed to study copper and zinc supplementation, no differences due to mineral supplementation were noted in growing pigs but McLaughlan et al, (1975) noted a severe transitory zinc deficiency in rats just prior to and at parturition which was attributed to very high phytate levels in RSM. Although results in growing pigs cannot be directly compared to rats at parturition, the report of McLaughlan et al (1975) indicates that factors other than glucosinolate may be important regarding utilization of RSM by animals.

Bell (1975) found no significant differences in pigs from feeding Bronowski RSM or SBM on performance or carcass characteristics but ADG, FI and FCE were significantly ($P<.05$) depressed on diets which contained Span, a low erucic acid, medium-high glucosinolate RSM of B. campestris type.

Studies by Orok et al (1975) showed that ADG, FI, and

FCE were significantly ($P<.05$) reduced when Span RSM completely replaced SBM in diets for pigs and rats. Bowland et al (1975) using double-low rapeseed meals from two sources found no significant effects of partial replacement of SBM by 00-RSM for pigs in the growing phase nor of complete replacement of SBM by 00-RSM in the finishing phase. In this report, all pigs were fed diets containing 11% of SBM during the starting phase from 4 to 9 weeks of age and 5.5% SBM during the growing phase from 9 to 14 weeks of age.

Crude fibre levels in RSM and SBM

In Western Canada, particularly, the SBM used as the main protein supplement for livestock diets is usually produced from dehulled soybeans. Theoretically, a comparison between dehulled SBM and RSM, which at the present time cannot be economically dehulled due to the small size of rapeseed, is not without bias. On the other hand, the facts are that dehulled SBM is the main protein source used in the feed industry and it is the standard against which alternative protein sources are compared in the field. Thus, although comparisons of RSM may be made against dehulled SBM, such comparisons should be evaluated in perspective of the materials being compared.

The significant implication regarding the amounts of hull in RSM is the direct relationship of hulls to crude

fibre (CF) levels and the inverse relationship of CF to DE (Drennan and Maguire, 1970; King and Taverner, 1975). Saben and Bowland (1971) published values of 12.65-13.25% CF for RSM. DE values were found to be 2900 kcal/kg. In the same experiment, CF and DE values were reported as 6% and 3300 kcal/kg respectively for dehulled SBM. Comparable values for SBM with hulls were given by NAS-NRC (1973) as 2.8% and 3300 kcal DE/kg.

Digestibility of RSM for pigs

Hussar and Bowland (1959b) did not observe any significant effects on apparent digestibility of dry matter, energy or nitrogen of pigs weighing 7, 28 or 60 kg, when fed diets containing 0, 2 or 10% RSM as an isonitrogenous replacement for SBM. The highest level of RSM did cause a non-significant depression in body weight gain. Manns and Bowland (1963) observed a significant reduction in digestibility of dry matter but not in energy or nitrogen digestibility for 34 kg pigs when 100% of supplemental protein came from RSM rather than SBM. Saben and Bowland (1971) in an extensive series of trials designed to specifically investigate DE levels in RSM, found DE levels of 3370 kcal/kg in the dry matter of RSM and 4370 kcal/kg for SBM. In a second report (Saben et al, 1971) corresponding values were 3210 and 4210 kcal DE/kg for RSM and SBM, respectively. May and Bell (1971), also in a large

comprehensive study, determined DE values on dry matter basis of 3355 kcal/kg for RSM but only 3734 kcal/kg for SBM. The difference in DE for SBM between these findings and those of Saben and Bowland (1971) and Saben et al (1971) may have resulted from use of dehulled 50% protein SBM by Saben and Bowland (1971) compared with SBM with hulls used by May and Bell (1971) as noted from the dietary ingredients table of these reports. Energy digestibility coefficients of 67% for RSM and 87% for SBM were observed by Saben and Bowland (1971) while May and Bell (1971) reported 69% and 79% for RSM and SBM, respectively.

Cho and Bayley (1970) have investigated apparent digestibilities in semi-purified diets using RSM or SBM as protein sources. Reductions were observed in coefficients of digestibility for dry matter, CP, energy and nitrogen of RSM vs SBM-based diets. Nitrogen retention and apparent biological value of RSM diets were lower than those for SBM diets. The data in the report of Cho and Bayley (1970) indicate that digestibility of nutrients in RSM may be only 85% of that in SBM. It is of interest to note that the SBM used by these workers was dehulled. CP was relatively less well digested in RSM than in SBM. Another factor in this work which may have influenced results was that diets were isocaloric on a gross energy basis but not on a DE basis, since DE coefficients were 74.9 for RSM but 85.3 for SBM-

based diets. Apparent digestibilities of amino acids ranged from 75-92.4% and were within the same range as those for other nutrients. Apparent digestibility of both lysine and methionine was 87% in RSM. For SBM, digestibility coefficients of amino acids ranged from 85-92% with a value for lysine of 90.4 although digestibility of methionine was only 79%. Sarwar et al (1975) similarly found true digestibilities of amino acids of Span RSM and certain RS isolates were less than those obtained for SBM or a soybean isolate for rats fed diets which were isocaloric on a gross energy basis. The other parameters of digestibility included by Cho and Bayley (1970) were not considered by Sarwar et al (1975). Reduction of digestibility was observed for RS isolates which should not have included appreciable amounts of fibre as well as for RSM compared with SBM or soybean isolates. The reduction of true digestibility for RS isolates was, however, less than with RSM, but weight gain of rats fed both RS and soybean isolates was less than the corresponding meals. This effect was attributed by Sarwar and Bowland to losses during the isolation process. The suggestion from this work was that lysine particularly, as well as nitrogen availability, was lower in RS derivatives than in soybean products. The effects of energy levels on these results cannot be evaluated since it is not known if the actual DE levels received by the animals were different.

No depression of was found for diets containing Bronowski RSM (Bowland, 1974a; Bell, 1975) or for two unlicensed 00-RSM varieties ccmpared with SBM (Bcwland, 1975; Bowland et al, 1975). Also, no depression of digestibility of diets containing Span RSM was observed by these authors. Sarwar and Bowland (1976) found that apparent digestibility of protein was 84% while apparent lysine digestibility was 78% with a level of 14% 00-RSM in the diet. With 7% supplementation of RSM in diets based on white wheat flour, digestibility cf lysine was 72%.

The general conclusion that can be drawn from these reports is that the digestibility coefficients of diets containing high levels of RSM may be reduced to a significant degree in comparison with de-hulled SBM-based diets. However, when fed at ccmmon levels of usage, no significant reductions of digestibility should occur in isocaloric diets. At high levels of supplementation, reduction of apparent digestibility may occur for dry matter, energy, nitrogen and amino acids as shown by the work of Manns and Bowland (1963), Cho and Bayley (1970) and Sarwar et al (1975).

In summary, the net effect of RSM in the diets of starting, growing and finishing pigs appears to be related to glucosinolate level with a marked difference in

performance of pigs fed low and high glucosinclate varieties of RSM. It is clear that reduction of levels of these toxic compounds greatly improves FI, ADG and FCE, even when RSM completely replaces SBM. It has, however, been noted that although significant differences were usually not observed when low glucosinolate Bronowski RSM was completely substituted for SBM, there were certain inconsistent results for the sexes (Bowland, 1974a), and with high and low hull fractions (Bowland, 1974b).

OBJECTIVES

The present experiments were designed to investigate the nutritive value of 00-RSM (cultivar Tower) for starting, growing and finishing pigs and to determine the effects of 00-RSM on thyroid functicn compared with commercial RSM and SBM.

PART 1. NUTRITIVE VALUE OF DOUBLE-LOW RAPESEED MEAL AS A SOURCE OF PROTEIN FOR STARTING, GROWING AND FINISHING PIGS

Introduction

Considerable information has been obtained with pigs and rats on the nutritive value of the low glucosinolate rapeseed cultivar Bronowski but information is limited on varieties which are agronomically better suited to Western Canada, and which will be used in commercial production of rapeseed in the future. Bowland (1975) and Bowland et al (1975) reported that 00-RSM could be satisfactorily used in diets for young pigs at much higher levels than were previously recommended for RSM with high glucosinolate levels. Moody et al (1976) reported similar results but Castell (1976) observed that performance was 7% less when pigs were fed diets containing 15% Tower RSM from the 1974 crop, compared with SBM. However, performance of pigs fed Echo or Target RSM, was 18% less than pigs fed SBM. These latter rapeseed cultivars are not low glucosinolate types. With the release for commercial production of the 00-RSM cultivar, Tower, it was considered desirable to extend the previous studies at The University of Alberta to a larger more definitive experiment including measures of growth, carcass composition, digestibility and thyroid hormone

levels.

The objectives of this study were to compare RSM from a low glucosinolate, low erucic acid cultivar Tower (00-RSM) and from commercially available rapeseed meal (C-RSM), from a low erucic acid, medium-high glucosinolate variety likely of B. campestris origin, as partial or complete replacements for SBM in the diets of starting, growing and finishing pigs.

Experimental

Animals and diets

A total of eighty 3-4 week old crossbred (Lacombe x Yorkshire) pigs from The University of Alberta Swine Research Unit averaging 5.3 kg in weight and with equal number of barrows and gilts were allotted to five experimental diets (Table 2). The experiment was carried out in two time periods (April to September, 1975 and July 1975 to January, 1976) with 40 pigs in each period. Data will be presented on the basis of a starting period from 4-10 weeks of age, a growing period from 10-15 weeks and finishing period from 15 weeks to market.

Pre-weaning management followed the standard practice at this unit as outlined by Aherne et al (1974). A standard creep feed was allowed during the suckling period and males

Table 2. Diet formulation in the starting, growing, and finishing periods

(percentage basis - as fed)

Ingredients, +%	Barley	Wheat	Tallow	SBM[≠] (48% CP)	OO-RSM (38% CP)	C-RSM (33% CP)
Starter period						
Diet no. 1	20.0	56.3	1.5	17.7	0	0
2	20.0	47.2	3.0	0	25.3	0
3	20.0	51.7	2.5	9.4	11.9	0
4	20.0	40.7	3.5	0	0	31.3
5	20.0	48.8	2.6	10.0	0	14.1
Grower period						
Diet no. 1	40.0	41.5	1.0	13.7	0	0
2	40.0	33.9	2.5	0	19.8	0
3	40.0	37.5	2.0	7.4	9.3	0
4	40.0	29.9	2.5	0	0	24.7
5	40.0	35.5	2.0	7.6	0	11.1
Finisher period						
Diet no. 1	46.0	40.0	1.0	9.2	0	0
2	42.1	40.0	1.5	0	12.6	0
3	44.0	40.0	1.3	4.8	6.1	0
4	38.9	40.0	1.8	0	0	15.5
5	42.7	40.0	1.4	4.9	0	7.2

+ All starting diets contained 0.5% iodized salt, 1.0% ground limestone, 1.5% calcium phosphate and 1.5% of a vitamin-trace mineral premix.* All growing and finishing diets contained 0.4% iodized salt, 1.2% ground limestone, 1.2% calcium phosphate and 1.0% of a vitamin-trace mineral premix.**

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

* The premix provided the following trace minerals: 88 ppm zinc, 76 ppm manganese, 294 ppm iron, 25 ppm copper and 2.8 ppm cobalt. It also provided per 100 kg diet: 440,000 I.U. Vitamin A, 55,000 I.U. Vitamin D, 1,100 I.U. Vitamin E, 1.10 g riboflavin, 2.20 g calcium pantothenate, 4.80 g niacin, 5.50 g choline chloride, 165 mg folic acid, 2 mg Vitamin B_{12} and 0.3 g of nitrofurizolidone.

** The premix provided the following trace minerals: 59 ppm zinc, 8 ppm manganese, 31 ppm iron, 2.7 ppm copper, and 0.3 ppm cobalt. It also provided per 100 kg diet: 293,000 I.U. Vitamin A, 37,000 I.U. Vitamin D, 370 I.U. Vitamin E, 0.30 g riboflavin, 0.60 g calcium pantothenate, 1.30 g niacin, 1.45 g choline chloride, 44 mg folic acid, and 0.3 ug Vitamin B_{12}.

were castrated at 10-14 days of age. All pigs were weaned at 3 weeks of age. An approximately one week adjustment period was allowed during which time pigs were assigned to treatment and introduced to the experimental diets. The experiment commenced at 4 weeks of age.

During the starting and growing phases, two pigs (one barrow, one gilt) were kept in each pen (0.6 x 1.2 m) on partially slotted concrete floors. Feed was available ad libitum from self-feeders. Two pairs of pigs which had been fed the same diet were grouped together during the finishing period in pens with concrete floors measuring 1.5 x 4.2 m. Individual feeding stalls were provided in the front 1.5 m section of the pen. Each pig was allowed access to the diet for two periods of 1 hour per day during the finishing phase. Water was available free-choice in each pen. Environmental temperature was maintained at 21-23 C.

Diets were formulated to be isonitrogenous and isocaloric on a DE basis and to meet the recommended nutritional requirements of pigs (NAS-NRC, 1973) during the three phases (Table 2). Proximate analyses of diets are given in Table 3. The experimental diets were based on barley and wheat and contained as supplemental protein sources either Tower double-low RSM (00-RSM) from the 1974 crop year, commercial RSM (C-RSM), SBM or 50:50 isonitrogenous combinations of 00-RSM or C-RSM plus SBM.

Table 3. Composition of diets - determined by analysis

	Dry matter %	Crude protein %	Gross energy kcal/kg	Calculated digestible energy kcal/kg	Crude fibre %	Calcium %	Phosphorus %	Oxazolidine-thione mg/g	Isothiocyanates mg/g
Starter period									
Diet no. 1	90.9	17.7	3987	3165	4.1	0.93	0.75	0	0
2	90.5	17.8	4175	3160	6.2	1.04	0.87	0.3	0
3	91.9	18.0	4030	3181	5.0	0.98	0.78	0.1	0
4	92.3	17.9	4051	3155	7.4	1.11	0.97	0.5	0.8
5	92.5	18.1	4018	3173	5.7	0.99	0.89	0.3	0.3
Grower period									
Diet no. 1	93.0	16.3	3899	3134	4.8	0.82	0.66	0	0
2	92.5	16.5	4041	3153	6.9	1.01	0.78	0.3	0
3	93.1	16.3	4013	3160	6.0	0.95	0.71	0.2	0
4	93.1	16.2	4049	3138	8.0	1.01	0.81	0.3	0.6
5	92.6	16.2	4012	3156	7.6	0.93	0.79	0.3	0.4
Finisher period									
Diet no. 1	92.6	14.1	3792	3125	5.7	0.87	0.66	0	0
2	92.6	13.9	3863	3152	6.7	0.97	0.71	0.2	0
3	92.6	14.1	3922	3125	5.9	0.83	0.69	0.1	0
4	92.3	13.9	3947	3124	6.6	1.01	0.75	0.4	0.4
5	92.8	14.4	3895	3128	5.9	0.69	0.71	0.2	0.2

Nutrient compcsition of the protein sources is presented in Table 4.

Diets were formulated to contain the following nutrient levels: starter, 18% CP and 3170 kcal DE/kg; grower, 16% CP and 3145 kcal DE/kg; and finisher, 14% CP and 3130 kcal/DE/kg.

Feed consumption and body weight were determined on a weekly basis throughout the experiment. Pigs were marketed through a commercial slaughtering plant as they reached an individual weight of 85 kg on the weekly weighing except that the lightest animal in each pen of four pigs was marketed when the next heaviest reached 85 kg. All carcasses, except one in the C-RSM group, were graded by Canadian Hog Carcass Valuation System (CDA, 1969). The animal not marketed failed to grow normally and was submitted for necropsy[1] at the termination of the experiment. No clinical or histological evidence of disease was found to account for the abnormally slow rate of growth of this pig.

Metabolic studies

Digestibility of diets

Estimates of apparent digestibility of energy and

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[1]Veterinary Services Branch, Alberta Agriculture, Edmonton, Alberta.

Table 4. Proximate analysis and amino acid composition of protein sources

Protein source	SBM* as fed %	SBM* in protein %	00-RSM as fed %	00-RSM in protein %	C-RSM as fed %	C-RSM in protein %
Dry matter	91.4		92.5		92.1	
Crude protein	48.6		38.6		33.2	
Fibre	4.6		12.3		13.1	
Fat	2.4		2.1		2.2	
Calcium	0.31		0.59		0.77	
Phosphorus	0.70		1.05		1.11	
Selenium (ppb)	371		1580		585	
Amino acids						
Essential						
Arginine	3.46	7.12	2.27	5.90	1.86	5.63
Histidine	1.29	2.66	1.05	2.74	0.90	2.74
Isoleucine	1.50	3.09	1.47	3.83	1.27	3.85
Leucine	3.57	7.37	2.64	6.88	2.19	6.62
Lysine	3.04	6.27	2.14	5.57	1.93	5.83
Methionine	0.66	2.86	0.74	2.47	0.64	3.83
Phenylalanine	2.43	8.14	1.52	6.43	1.31	6.44
Threonine	1.99	4.13	1.70	4.45	1.46	4.20
Valine	2.34	4.80	1.93	5.01	1.64	4.97
Non-essential						
Alanine	2.08	4.28	1.70	4.44	1.45	4.37
Aspartic acid	5.45	11.23	2.74	7.16	2.26	6.80
Cystine	0.38	0.78	0.48	1.25	0.32	0.95
Glutamic acid	8.13	16.73	6.39	16.68	5.34	16.09
Glycine	2.05	4.22	1.88	4.91	1.60	4.81
Proline	2.53	5.20	2.46	0.42	2.13	6.43
Serine	2.45	5.04	1.69	4.41	1.40	4.22
Tyrosine	1.52	3.13	0.69	2.52	0.81	2.43
Oxazolidinethione mg /g	--	--	0.9		2.0	
Isothiocynates mg /g	--	--	0.2		3.4	

* SBM= soybean meal; 00-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

nitrogen were determined between 9 and 10 weeks of age. Digestibility determinations were made using a male and a female in each of the 2 replications within the 2 time periods. The total collection method outlined by Castell and Bowland (1968) was followed except that 10 metabolism crates were used in each replication.

A 3-day adjustment period was allowed followed by a 3-day collection of feces and urine. Pigs were fed 3 times per day during the digestibility trial at a level of 90% of the mean daily feed intake of the pair of pigs in the same pen in the previous week. The pigs weighed an average of 15.1 kg during the period of collection.

The entire 3-day feces of each pig was stored and representative samples were oven-dried[1] at 60 C for 72 hours and then ground in an 8-inch laboratory mill[2]. Representative samples of urine were freeze-dried[3] (shelf temperature -38 C for 48 hours) prior to analytical determinations.

Gross energy was measured for feed, feces and urine using a Parr adiabatic oxygen bomb calorimeter[4].

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[1]Style V31, Dispatch Oven Co., Minneapolis, Minn., U.S.A.
[2]Christy and Norris Ltd., Chelmsford, England.
[3]Repp Sublimator, Model SRC42, Division of Virtis Co., Inc., Gardiner, New York.
[4]Parr Instrument Co., Moline, Illinois. Temperature changes registered by a Brown Electronik Recorder, Minneapolis-Honeywell Regulator Co., Philadelphia, Penn.

Appropriate analyses of dry matter, total Kjeldahl nitrogen and CF of feed, feces and urine, were made according to the methods of A.O.A.C. (1970). A commercial "Kel-Pak"[1] was used to supply the catalyst for nitrogen determination and ammonia was collected in 4% boric acid.

Amino acid analyses

Amino acid analyses of the diets (Table 5) and feces were obtained with a Type 5AH amino acid analyzer[2] following the methods outlined by Orok (1973).

Thyroid hormone studies

Following the digestibility trials, all pigs in the study were bled by anterior vena cava puncture (Carle and Dewhirst, 1942) 4 hours after feeding a meal based on the average daily feed intake (ADF) of the previous week. All bleedings were preceded by an overnight fast of 15-16 hours. All feed not consumed within 30 minutes was removed and the amount consumed was recorded. Approximately 15 ml of blood was withdrawn using 17-gauge, 4-inch (10 cm) needles and 20 ml plastic syringes. Blood was transferred to test tubes and allowed to stand for 20 minutes prior to centrifugation at 2,500 rpm (1.01 g) for 10 minutes. Serum was then stored at -20 C in sealed tubes for 1-3 months prior to analysis.

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[1]Matheson Scientific, East Rutherford, New Jersey. This supplied a mixed catalyst containing
[2]Japan Electron Optics Co., Ltd., Tokyo, Japan.

Table 5. Amino acids provided by experimental diets and amino acid requirements of starting pigs

Treatment no.	1	2	3	4	5		
Protein source	SBM≠	OO-RSM	OO-RSM +SBM	C-RSM	C-RSM +SBM	Amino Acid Requirements (NAS -NRC, 1973) (5-10 kg)	(10-20 kg)
Crude protein %	17.7	17.8	18.0	17.9	18.1		
Amino acids %							
Essential							
Arginine	1.02	0.96	0.99	0.93	.98	0.28	0.23
Histidine	0.42	0.43	0.42	0.41	0.42	0.25	0.20
Isoleucine	0.68	0.64	0.67	0.64	0.66	0.69	0.56
Leucine	1.21	1.17	1.39	1.31	1.17	0.83	0.68
Lysine	0.84	0.80	0.82	0.87	0.87	0.96	0.79
Methionine	0.25	0.29	0.27	0.31	0.28	--	--
Phenylalanine	0.80	0.71	0.75	0.71	0.75	--	--
Threonine	0.62	0.68	0.65	0.69	0.65	0.62	0.51
Valine	0.79	0.84	0.82	0.82	0.80	0.69	0.59
Methionine + cystine	0.42	0.50	0.47	0.48	0.45	0.69	0.56
Phenylalanine + tyrosine	1.19	1.07	1.13	1.06	1.12	0.69	0.56
Non-essential							
Alanine	0.71	0.73	0.71	0.73	0.71		
Aspartic acid	1.49	1.17	1.29	1.15	1.33		
Cystine	0.17	0.21	0.20	0.17	0.17		
Glutamic acid	3.63	3.53	3.56	3.45	3.62		
Glycine	0.72	0.79	0.75	0.81	0.76		
Proline	1.30	1.39	1.31	1.32	1.35		
Serine	0.82	0.76	0.78	0.76	0.79		
Tyrosine	0.39	0.36	0.38	0.35	0.37		

≠ SBM = soybean meal; OO-RSM = rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM = commercial rapeseed meal.

Analyses of triiodothyronine uptake (T-3 uptake), triiodothyronine radioimmunassay (T-3 RIA) and tetraiodothyronine (T-4) levels were conducted by a commercial laboratory[1]. T-3 uptake was determined by the method of Leonards (1974) which is based on the competition between serum thyroxine binding protein (TBE) and Sephadex G-25 for ^{125}I-triiodothyronine. This method estimates the percentage of free T-3 by determining the excess binding sites on TBE in competition with the Sephadex column for ^{25}I-T-3. T-3 RIA was determined by radioimmunoassay procedure of Chopra et al (1971) and T-4 by the simplified radioimmunoassay as outlined by Krahn et al (1974). Both these procedures depend upon dissociation of thyroid hormones from thyroxine binding proteins and reaction with a fixed quantity of specific T-3 and T-4 antigens with ^{125}I-T-3 or T-4.

A value designated T-7 was calculated as a free thyroxine index:

$$T\text{-}7 = \frac{\text{T-3 uptake} \times \text{T-4}^2}{100}$$

Howorth and MacLagan (1969) suggested that this ratio was valuable to indicate relative changes in thyroid hormone

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[1]Dr. P.M. Krahn, Box 87, R.R.#2, Site 9, Sherwood Park, Alta.
[2]Dr. S. Hanson and Associates, Medical Laboratory, Edmonton, Alberta.

levels where either T-3 or T-4 may be elevated and is therefore a good indicator of thyroid metabolism.

Glucosinolate determinations

Levels of glucosinolates for both the 00-RSM and C-RSM used in this study as well as glucosinolate levels of all diets were determined using the method of Youngs and Wetter (1957)[1]. In this method oxazolidinethione (OZT) is measured spectrophotometrically following isolation in diethyl ether from a methyl chloride system and isothiocyanates are measured by comparing the retention times with known standards on a gas-liquid chromatograph. Results of these analyses are included in Table 3 for the diets and in Table 4 for the 2 sources of RSM used in this experiment.

Statistical analyses

Data were analyzed statistically using a multi-way analysis of variance (ANOVA) program available from The University of Alberta Computing Centre. Means were compared using Duncan's Multiple Range Test (Steel and Torrie, 1960) preceded by a significant F-test (Waldo, 1976). A probability of 0.05 was selected as the point of significance between means. The sources of variation were 5 diets and 2 sexes. All sources of variation except periods,

[1]Analyses supplied by Dr. Z.P. Kondra, Plant Science Dept., The University of Alberta, Edmonton, Alberta.

replicates and animals were considered as fixed. Notations used to indicate level of significance are: *(P<.05), **(P<.01), ***(P<.001). Means not significantly different bear the same superscript cr no superscript.

In period 2, one pig fed the control diet died during the starting phase of causes unrelated to the experimental treatment and one pig fed the C-RSM diet grew abnormally slowly and was removed frcm the experiment. Mean performance and carcass values for the same dietary treatment, sex and period were substituted and two degrees of freedom for the error term were removed.

During the finishing period, treatment mean squares were initially tested against pen mean squares since four pigs on the same diet were contained in a single pen with individual feeding stalls. The pen mean square was tested against the residual mean square and found to be non-significant, subsequently the two terms were pooled and used as the error mean square. Period and replicate mean squares were tested against the period x replicate mean square.

Results and Discussion

The results are considered under the following categories: live animal performance, digestibility, carcass characteristics and thyroid hormone levels.

Live animal performance

The three phases of growth considered in this experiment will be presented, followed by a summary of the overall performance from 4 weeks of age to market weight at 85 kg.

Starting Phase

During the starting phase from 4 to 10 weeks of age, pigs fed the diets containing SBM or 50:50 isonitrogenous mixture of 00-RSM and SBM (00-RSM+SBM) showed similar ADF, ADG and feed/gain ratio (F/G) as shown in Table 6.

Replacement of all SBM by 00-RSM, C-RSM or a 50:50 isonitrogenous mixture of C-RSM and SBM (C-RSM+SBM) resulted in a significant ($P<.05$) decrease in ADF. With the exception of pigs fed the C-RSM diet, ADG and F/G were not significantly different from those observed for the pigs fed the SBM diet but were, however, numerically less for pigs fed the 00-RSM and C-RSM+SBM diets. Complete replacement of SBM by C-RSM resulted in marked depression of ADG and F/G. Also, pigs fed C-RSM weighed significantly ($P<.05$) less at 10 weeks than pigs fed other diets. Pigs fed 00-RSM and C-RSM+SBM weighed somewhat less than those fed SBM or 00-RSM+SBM but differences were not statistically significant.

No significant sex differences were observed in the starting period. Pigs were penned in pairs of 1 male and 1

Table 6. Feed intake, average daily gain and feed:gain of pigs in starting, growing and finishing phases

Treatment no.		1	2	3	4	5	Sex		Period		Grand	
Protein source		SBM[≠]	00-RSM	00-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM[+]
Number of pigs		15	16	16	15	16						
Initial wt.	kg	5.3	5.5	5.3	5.3	5.2	5.1	5.6	5.1	5.6	5.4	0.21
10 wk. wt.	kg	20.7^{a}	18.4^{a}	20.5^{a}	13.9^{b}	18.8^{a}	17.8	19.1	19.9*	17.1	18.5	0.98
15 wk. wt.	kg	43.1^{a}	37.7^{b}	42.5^{ab}	28.7^{c}	38.9^{ab}	35.9	40.5**	39.2	37.1	38.2	1.63
Final wt.	kg	85.7	84.7	84.9	81.5	84.8	82.9	85.7*	84.7	83.9	84.3	1.35
Starting period												
Avg. daily feed	kg	0.80^{a}	0.70^{b}	0.78^{a}	0.69^{b}	0.72^{b}	-	-	0.78	0.70	0.74	0.02
Avg. daily gain	kg	0.37^{a}	0.31^{a}	0.36^{a}	0.21^{b}	0.32^{a}	0.30	0.33	0.35**	0.27	0.31	0.02
Feed/gain ratio		2.20^{b}	2.32^{b}	2.21^{b}	3.54^{a}	2.28^{b}	-	-	2.28	2.74**	2.51	0.09
Growing period												
Avg. daily feed	kg	1.67_{a}	1.63_{b}	1.68_{a}	1.56_{c}	1.55_{ab}	-	-	1.57	1.66	1.62	0.04
Avg. daily gain	kg	0.64^{a}	0.55_{b}	0.63^{a}	0.42^{c}	0.58^{bc}	0.51	0.61***	0.55	0.57	0.56	0.02
Feed/gain ratio		2.63^{c}	2.96^{b}	2.67^{c}	3.76^{a}	2.72^{bc}	-	-	2.89	3.01	2.95	0.09
Finishing period												
Avg. daily feed	kg	2.36^{a}	2.24^{ab}	2.25^{ab}	1.95^{c}	2.13^{b}	2.04	2.33***	2.18	2.19	2.19	0.06
Avg. daily gain	kg	0.62^{a}	0.58^{a}	0.58^{a}	0.53^{b}	0.58^{a}	0.56	0.60**	0.59*	0.57	0.58	0.01
Feed/gain ratio		3.80	3.87	3.87	3.69	3.64	3.64	3.91**	3.68	3.87*	3.77	0.10
Overall performance												
Days-to-market		166.7^{c}	178.9^{b}	170.2^{bc}	198.6^{a}	177.2^{b}	182.9*	173.8	175.7	180.9	178.3	3.23
Avg. daily feed	kg	1.43_{a}	1.40_{b}	1.40_{ab}	1.35_{c}	1.34_{b}			1.37	1.40	1.34	0.03
Avg. daily gain	kg	0.49_{b}	0.45_{b}	0.47_{b}	0.39_{c}	0.45_{b}	0.43	0.47***	0.46*	0.44	0.45	0.01
Feed/gain ratio		2.95^{b}	3.15^{b}	2.99^{b}	3.54^{a}	2.97^{b}			3.01	3.23**	3.12	0.08

≠ SBM = soybean meal; 00-RSM = rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM = commercial rapeseed meal.

+ SEM = Standard error of means = $\sqrt{\frac{\text{Error mean square}}{n}}$

a, b, c Means in the same row with the same letter or no letter are not significantly different at $P<0.05$.

female in the starting period, thus sex effects on ADF could not be determined nor could F/G te calculated.

Pigs in period 1 (April-September, 1975) gained significantly (P<.01) faster, consumed significantly (P<.01) less feed per unit of body weight and were significantly (P<.05) heavier at 10 weeks of age than pigs during period 2 (July, 1975-January, 1976).

The differences for ADG and F/G between periods are substantial although the same facilities and procedures were employed in both periods. Pigs in period 2 were started during the summer months which may have resulted in undesirable conditions in the barns although environmental temperatures were maintained within the desired range (21-23 C). Inspection of the weekly mean weights during the starting phase shows that a period of slower growth occurred during the seventh and eighth weeks of age in period 2. This interval of slower growth did not occur in period 1, which may account for the period differences. As no pigs were slaughtered at this time, it was not possible to check whether any acute or chronic disease condition existed.

An explanation of the slightly slower rate of growth of pigs fed 00-RSM compared with pigs fed SBM appears to be related to a significant (P<.05) reduction in ADF and inferior conversion of feed into body tissue although

differences between diets were not statistically significant for the latter parameter. The same explanation may also account for the similar results observed when 50% of the SBM was replaced by C-RSM. Differences between 00-RSM and C-RSM+SBM diets were not significant for ADF, ADG or F/G although these parameters were numerically, but not significantly inferior tc performance of pigs fed the SBM and 00-RSM+SBM diets.

Reports by Hussar and Bowland (1959a) and Manns and Bowland (1963) suggested that no depression of performance occurred when up to 10% of RSM was included in pig starting diets. At levels greater than 10% RSM, significant depression of growth, feed intake and feed conversion efficiency was observed. The RSM used in these early studies had high glucosinolate levels. Manns and Bowland (1963) reported OZT levels of 5.6 mg/g and ITC of 4.2 mg/g.

Bowland (1974a) and Bell (1975) using the low glucosinolate RSM cultivar Bronowski, as well as Castell (1976) using Tower RSM, reported depression of performance of pigs fed low glucosinolate RSM compared with SBM but such effects were much less severe than with Span RSM. However, Bowland (1975), using a 00-RSM which has now been licensed as Tower from the 1973 crop year, found 00-RSM was satisfactory as a complete replacement for SBM for young pigs. Growth of pigs fed 00-RSM as the sole source of

supplemental protein in the current study was somewhat slower but not significantly less than pigs fed SBM although ADF was significantly ($P<.05$) less. The partial replacement of SBM by 00-RSM resulted in performance not significantly different but slightly less than SBM-fed pigs. Perfcrmance of pigs fed the C-RSM+SBM diet was similar to that of pigs fed the 00-RSM diet.

One factor which must be kept in mind in interpretation of the results of the present study during the starting phase is that the levels of RSM in these diets were very high (Table 2). The amounts of RSM used in the 00-RSM and 00-RSM+SBM diets were 25.3 and 11.9% and 31.3 and 14.1%, respectively for the C-RSM and 00-RSM+SBM diets.

The high glucosinolate levels of RSM are generally considered to be the main cause cf the reduced performance when large amounts of RSM are fed (Bowland, 1965). The nutrient composition of the two protein sources is shown in Table 4. This indicates that low levels of total glucosinolates were present in 00-RSM but rather high levels in C-RSM. Of the gluccsinclates in 00-RSM, OZT comprised the major part. Krusius and Peltola (1966) and Lo and Bell (1972) have shown that OZT is a more potent goitrogen for rats than ITC. The results of the above mentioned researchers can be predicted based on the site of action of these two glucosinolates as reviewed earlier. OZT inhibits

the iodination of tyrosine as well as the tyrosine coupling reaction to form thyronine whereas the main effect of ITC is to interfere with the uptake of iodide from the plasma. The latter is a reversible reaction which can be overcome in some cases by higher iodine supplementation (Green, 1971).

Krusius and Peltola (1966) found that 0.5 ug/day of pure OZT when fed in the water was sufficient to cause thyroid enlargement in rats. Also, levels of 0.5 mg/day of OZT in a single dose interfered with ^{131}I uptake. Lo and Hill (1971b) found that diets containing 0.3 mg/g of total glucosinolates from Brongwski RSM resulted in a more rapid uptake of ^{125}I from the plasma and in a slower release of ^{125}I as thyroid hormone compared with rats fed casein. Josefsson (1974), on the other hand, reported that growth of mice was not affected if the total glucosinolate level in the diet from RSM was less than 1 mg/g. The difference in these results may be explained by the fact that Krusius and Peltola (1966) fed pure compounds in the water whereas Josefsson (1974) fed heated RSM containing intact glucosinolates. It must also be kept in mind that Krusius and Peltola (1966) investigated thyroid response to OZT in rats whereas Josefsson and Munk (1973) fed RSM to mice. Thus, although routes of administration of glucosinolates, parameters measured and species tested were different, these reports do give some indication of the range of

glucosinolates which may affect the thyroid and also indications of levels at which live animal performance may be affected. No similar studies have been made with pigs. It is not known if the levels of glucosinolates, particularly OZT, found in the 00-RSM diets (Table 3) are sufficiently high to alter thyroid metabolism in pigs but the possibility cannot be completely ruled out.

RSM has a high CF level (Table 4) thus the recommendation that maximum CF levels should not exceed 3% for young pigs (ARC, 1967) was exceeded. As can be seen in Table 3, the fibre level for diets with complete replacement of SBM by RSM resulted in CF levels of 6.2% for 00-RSM and 7.4% for the C-RSM diet. In the case of 00-RSM this high level of fibre in light of the very high levels of RSM used as a complete substitution for SBM could have been a major cause of the poorer growth of starting pigs compared with animals fed SBM-based diets. Although the possibility cannot be ruled out that the level of residual glucosinolates present in the 00-RSM used in this study could have affected performance of pigs fed the 00-RSM diet, the fact that the depression which did occur was not large would indicate the cause was some factor with a consistent but small effect. Such effects were demcnstrated for digestibility of the 00-RSM diet. Differences in performance of pigs fed 00-RSM diets compared with SBM,

although significant (P<.05) for ADF, are not large. Because of the inverse relationship of DE and CF (Drennan and Maguire, 1970; King and Traverner, 1975), a major effect of high fibre levels is to lower DE. The diets in the present study were formulated to be isocaloric on a DE basis by the addition of fat using data of Saben et al (1971) and May and Bell (1971). The effects of high levels of CF should be evident in differences in digestibility between SBM and RSM diets. Such differences should then be noted in studies of digestibility which will be discussed later.

The high levels of fibre in C-RSM cannot account for the severe depression of ADG and F/G ratios observed in pigs fed this diet. ADF was not significantly different from 00-RSM or C-RSM+SBM diets but ADG and F/G were markedly depressed (P<.05) compared with all other diets. In a comparative trial where animals and environmental conditions are similar, growth can be considered largely as a function of feed intake and of the conversion ratio of feed into animal body tissue. Thus, the severe depression in ADG of pigs fed C-RSM diets can be attributed to a severe depression of F/G ratio. Considering the well-known growth depressing effects of high glucosinolate RSM in pigs and the high levels of RSM used in the C-RSM diet, the results in the present experiment are not unexpected. Manns and Bowland (1963) found that 10% of high glucosinolate RSM

depressed performance of young pigs and the amounts of C-RSM used in the present study greatly exceeded that amount.

Isonitrogenous replacement of 50% of the SBM by C-RSM resulted in a significant ($P<.05$) improvement of ADG and F/G compared with C-RSM. ADF was significantly ($P<.05$) and ADG and F/G slightly, but not significantly inferior to SBM or 00-RSM+SBM diets. Overall performance is quite similar to that of pigs fed 00-RSM diets. It is likely that glucosinolate levels in the C-RSM+SBM diet affected performance, but because lower levels of C-RSM were used, the results are similar to the results of earlier work reviewed by Bowland (1965) where a mixture of SBM and RSM often produced performance similar to SBM diets.

Growing phase

Results during the phase from 10 to 15 weeks of age show similar trends to those observed in the starting phase and are summarized in Table 6. ADF was not significantly different for any diet although intake of C-RSM and C-RSM+SBM was slightly but not significantly less than other diets. ADG was greatest for the SBM and 00-RSM+SBM diets with the 00-RSM significantly ($P<.05$) less than the first two diets. C-RSM diets produced the lowest gain ($P<.05$). F/G was significantly ($P<.05$) less for 00-RSM and C-RSM+SBM compared with SBM and 00-RSM+SBM diets. F/G of pigs fed the C-RSM diet was markedly inferior to other diets, as in the

starting phase (P<.05). Body weight at the end of the growing phase at 15 weeks was significantly (P<.05) less for pigs fed 00-RSM compared with pigs fed the SBM diet. However, weight of pigs fed C-RSM was significantly (P<.05) less than that of pigs fed all other diets.

Significant (P<.01) sex effects were noted during the growing phase. Barrows gained an average of 0.61 kg/day while gilts gained 0.51 kg/day. This finding is typically observed in pig experiments during the growing phase (Bowland, 1974a; Bell, 1975). It was not possible to determine sex effects for ADF or F/G because limitation of facilities made it necessary to house pigs in pairs of 1 male and 1 female as in the starting phase.

Unlike the starting period, no significant differences between the two periods were noted for ADF, ADG or F/G ratio.

ADG and F/G of pigs fed 00-RSM were significantly (P<.05) inferior to pigs fed SBM and 00-RSM+SBM diets during the growing phase. However, for the C-RSM diet the depression was not as marked as during the starting phase although ADG and F/G were significantly (P<.05) less than pigs fed other diets. Feed intake was similar for 00-RSM and SBM diets but was slightly reduced, although not significantly, for both diets with C-RSM. F/G of pigs fed

C-RSM+SBM was intermediate compared to pigs fed 00-RSM and SBM-based diets.

The similarity of trends in performance during the growing phase to those in the starting phase is evident in the moderate depression of growth of pigs fed 00-RSM and C-RSM+SBM but severe depression of pigs fed C-RSM diets compared with pigs fed SBM diets. In all cases, however, the depression was less severe than during the starting phase for pigs fed the C-RSM diet. Whether this effect was due to the lower levels of RSM used in the diets or is an age-related response in that the effects of RSM causes less interference with growth as the animal grows older or due in part to both factors is not known.

Finishing phase

The results of ADF, ADG and F/G ratio during the finishing phase are also presented in Table 6. ADF of the pigs receiving the diets containing SBM, 00-RSM and 00-RSM+SBM were not significantly different. Intake of the C-RSM diet was significantly ($P<.05$) less than all other diets and intake of the C-RSM+SBM was intermediate between SBM and C-RSM. No significant differences in ADG were apparent for SBM, 00-RSM, 00-RSM+SBM or C-RSM+SBM diets. Gain of pigs on the C-RSM diet was significantly ($P<.05$) less than that of pigs fed all other diets.

Results of F/G for finisher are somewhat different from the starting and growing phases in that no significant differences were observed for this parameter. However, pigs fed C-RSM and C-RSM+SBM tended to consume the least amount of feed per unit of gain which is the opposite of the situation in the starting and growing phases.

It is apparent that the rate of growth of pigs fed the C-RSM diet was affected less during the finishing than in earlier phases of this experiment. The improved F/G of pigs fed C-RSM compared with pigs fed other diets during this phase may be accounted for in the relatively long time these pigs were fed the finishing diet. All pigs in each period were moved to the finishing pens on the same day, thus pigs fed C-RSM weighed less than pigs fed the other diets and consequently a greater proportion of the total weight gained during the trial is accounted for during the finishing period. Since it is evident from the data in Table 6 that greater amounts of feed were required per unit of gain as the animals grew older, animals which were lighter at the start of this phase would have a greater proportion of the more efficient growth period at lighter weights accounted for in the finishing period.

Sex effects during the finishing period were similar to the growing period. Barrows had significantly higher ADF ($P<.001$), ADG ($P<.01$) and inferior F/G ($P<.01$) compared with

females. ADG and F/G were significantly ($P<.05$) better in period 1 compared with results in period 2 during this phase.

The previously observed effects of ADF and F/G reflected in values of ADG are seen in the finishing period, as in earlier phases. Although the best F/G was noted for C-RSM and C-RSM+SBM diets, the depressed intake of the C-RSM diet appeared to have resulted in a reduction of ADG compared with other diets ($P<.05$). It must be noted, however, that the differences in performance were all much less than in the starter or grower phase indicating that the deleterious effects of RSM were less severe with older animals. Another possibility is that the lower levels of RSM required to meet the protein levels during this phase accounted for the less severe effects particularly in pigs fed the C-RSM diet. As was indicated previously the effects of these two factors cannot be differentiated in this experiment.

An important observation during the finishing phase is that ADF, ADG and F/G of pigs fed 00-RSM are much less severely depressed than in the starting and growing phases. This observation is consistent with the previously mentioned possible involvement of high CF levels leading to a reduction in digestibility. It is known that high CF levels cause less depression of performance in older pigs than in

young pigs (ARC, 1967).

Comparison of the data during the growing and finishing phases indicates that some restriction of growth in all treatments probably occurred during the finishing phase. ADG was virtually the same as in the growing phase, whereas it would be expected to be more rapid during the finishing phase (NAS-NRC, 1973). In this trial the animals were individually fed during the finishing period for two 1-hour periods per day. In large studies conducted at several centres in England, Braude (1971) reported that rate of growth of growing-finishing pigs was not affected by feeding two or three times daily compared with ad libitum feeding but apparently pigs were not fed individually as in the present study. However, previous work at The University of Alberta (Bowland, 1966) suggested that performance may be lowered by individual feeding two times daily vs ad libitum feeding. Also, Bell (1975) reported that pigs fed Bronowski RSM showed a 16% increase in feed intake and 10% faster growth when fed ad libitum as compared with those fed 3 times daily for a total period of one hour. A factor that may explain the growth rate depression observed as a result of individual feeding in the present study is that water was not available during the two feeding periods. Pigs were usually observed to be very thirsty when let out of the individual feeding pens. Water was not available to pigs

during the feeding pericd in the experiments reported by Bell (1975). One factor which must be kept in mind is that although the level of feeding in the present work and that of Bell was obvsiously restrictive for all pigs. The intake of pigs fed the C-RSM diet in the present study appeared to be less than that of pigs fed cther diets. Thus, factors such as palatability of the C-RSM may have caused a reduction of feed consumption even under restricted feed intake.

Overall performance

The treatment order for number of days required to reach market weight closely approximated the order for ADG, as would be expected (Table 6). Pigs fed the SBM diet were shipped significantly ($P<.05$) earlier than pigs fed other diets, except 00-RSM+SBM fcllowed by pigs fed 00-RSM+SBM, 00-RSM and C-RSM+SBM ($P<.05$). Pigs fed the C-RSM diet took significantly ($P<.05$) longer than any other pigs to reach market weight. This parameter does reflect in a rather dramatic and meaningful way the differences in growth rate. Pigs fed 00-RSM and C-RSM+SBM on the average took 12 and 11 days longer, respectively to reach 85 kg while pigs fed C-RSM required 22 days longer than those fed SBM.

No significant differences were observed for ADF but ADG of pigs fed 00-RSM and C-RSM+SBM was significantly ($P<.05$) less than for pigs fed the SBM diet. ADG and F/G of

pigs fed the C-RSM diet was significantly (P<.05) inferior to pigs fed other diets. Pigs fed the 00-RSM diet tended to show a poorer conversion efficiency than pigs on the SBM diet or partial substitution of SBM with either source of RSM, but the differences were not significant.

Sex differences for the overall data were similar to the observations during the growing and finishing phases with significantly inferior results for gilts compared with barrows for ADG (P<.001), and days-to-market (P<.01). As was indicated previously, sex differences usually occur in swine nutrition trials, with ADF and ADG of gilts being inferior to barrows, and F/G being better.

Period effects were significant for ADG (P<.05) and F/G (P<.01) which were better in period 1 than in period 2. No significant differences were noted in ADF and days-to-market between the periods on an overall basis.

The results of the present study agree with the work of Moody et al (1976) that partial replacement of SBM with 00-RSM does not result in any statistically significant reduction of ADF, ADG or F/G ratio. In the present study, however, performance of pigs fed the SBM diet tended to be consistently better than pigs fed 00-RSM+SBM. Castell (1976) found that 15.6% 00-RSM as a partial replacement for SBM caused a 7% reduction in performance which is greater

than in the present study, even for starting pigs. Bowland (1975) found that 00-RSM could serve as a complete replacement for SBM but in the present study moderate depression in ADF, ADG and F/G was noted although such differences were not statistically significant in all cases. Higher levels of 00-RSM were used in the present study than in any of the earlier experiments which would tend to magnify any differences of nutrient content of the protein sources. Also, the present work as well as that reported by Moody et al (1976) and Castell (1976) are based on work carried out with RSM of the 1974 crop year. The work of Bowland (1975) and Bowland et al (1975) was carried out with meal of the 1973 crop year. The year-to-year variation may account at least in part, for the apparent differences between experiments.

Digestibility studies

Apparent digestibility of diets

Apparent digestibility of energy and nitrogen are presented in Table 7. In both periods, pigs receiving C-RSM were significantly ($P<.05$) lighter in weight than those fed other diets. Because of the lower weight of these pigs, feed consumption of the C-RSM diet was less than other diets. Also pigs in period 1 weighed significantly ($P<.001$) more than in the digestibility trial in period 2. Results were, however, quite consistent and uniform within treatment

Table 7. Apparent digestibility of energy, nitrogen

Treatment no.	1	2	3	4	5	Sex		Period		Grand	
Protein source	SBM[≠]	00-RSM	00-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM[+]
Number of pigs	8	8	8	8	8						
Average body wt kg	15.5[a]	15.5[a]	16.8[a]	12.2[b]	15.2[a]	15.1	15.0	17.8***	12.3	15.0	.85
Digestible energy %	85.1[a]	81.5[bc]	84.0[ab]	80.9[c]	83.7[ab]	83.4	82.7	82.4	83.7	83.0	.81
Metabolizable energy %	82.9[a]	79.2[bc]	81.5[ab]	78.5[c]	81.4[ab]	81.1	80.3	79.9	81.5	80.7	.85
Digestible nitrogen %	83.7[a]	79.9[b]	83.2[a]	79.8[b]	82.3[ab]	81.9	81.6	81.4	82.1	81.8	.95
N retained/DN %	63.3[b]	68.2[ab]	62.9[b]	72.2[a]	67.2[ab]	68.5*	65.0	66.1	67.4	66.8	1.78
N retained/N intake %	52.9	54.7	52.3	57.6	55.4	56.2*	53.0	53.8	55.4	54.6	1.67
DE/kg diet kcal	3365	3370	3379	3281	3367	3366	3338	3355	3350	3352	32.09
ME/kg diet kcal	3279	3282	3280	3182	3274	3277	3242	3256	3267	3259	34.53
DN/kg diet g	23.5[ab]	22.6[b]	24.0[a]	22.9[b]	23.9[a]	23.5	23.4	23.1	23.7	23.4	.30

[≠] SBM = soybean meal; 00-RSM = rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM = commercial rapeseed meal.

[+] SEM = Standard error of means.

a, b, c. Means inthe same row with the same letter or no letter are not significantly different at P<.05.

groups. Several authors at this and other stations have not found any effects of weight on digestibility within the limits of 19-60 kg (Cunningham et al, 1962; Lawrence, 1967; Saben et al, 1971; Bowland and Hardin, 1973; Bowland, 1974a), thus the differences in body weight should not have influenced the results.

Digestible energy (DE), metabolizable energy (ME) and digestible nitrogen (DN) were significantly ($P<.05$) lower for pigs fed the 00-RSM and C-RSM diets than for pigs fed the SBM diet. DE and ME of the 00-RSM diet were not significantly different from diets with partial replacement of SBM by either source of RSM. DN of 00-RSM and C-RSM diets was reduced ($P<.05$) compared with the SBM and 00-RSM+SBM diets. Digestibility of the diets with 50% substitution of SBM with either source of RSM was intermediate between the other 3 diets. Nitrogen retained/DN was greatest for the C-RSM diet and least for SBM or 00-RSM+SBM. Differences between the C-RSM diet and SBM and 00-RSM+SBM diets were significant ($P<.05$). The 00-RSM diet was intermediate. No significant differences due to dietary treatment were evident in nitrogen retained/nitrogen nitrogen intake. DN/kg of diet was significantly ($P<.05$) greater for the mixtures of protein sources than for either diet with complete substitution of SBM by RSM, while the SBM diet was intermediate. DE and

ME/kg of diet were not significantly affected by treatment. However, mean values for C-RSM for both parameters of energy digestibility are approximately 100 kcal less than other diets.

Manns and Bowland (1963) observed a non-significant depression in DN and DE with diets containing 15.6% RSM as a complete replacement for SBM. No depression was noted from 25 or 50 percent substitution of SBM by RSM. Cho and Bayley (1970), obtained lower digestibility of energy and nitrogen in diets supplemented with 9.6% RSM compared with those supplemented with SBM. Bowland (1974a, 1975) found no depression of energy or nitrogen digestibility with either low-glucosinolate or Span RSM compared with SBM.

Sex effects were not significant except for NR and N retained/DN ($P<.05$). Greater retention of nitrogen was observed for females compared with males. Orok et al (1975) reported similar effects. Period effects were not significant. A significant sex x diet ($P<.05$) interaction occurred for all energy and nitrogen digestibility parameters. Inspection of the data suggests that a lower overall digestibility may have occurred in the 00-RSM diet for males than for females. This effect was not apparent for other treatments and was not found in digestibility studies in Part 2 of this thesis nor in Part 3 with rats.

Bowland (1971, 1972) found significant sex differences for DN and DE coefficients of pigs fed RS or RSM compared with pigs fed SBM but not in later work using 00-RSM or Span RSM (Bowland, 1974a; 1975). Orok et al, (1975) found N digestibility coefficients, N retention as a percentage of intake and N retained/DN were all greater for gilts than barrows which was similar to the present experiment. Thus, it appears that differences between sexes may be noted in digestibility studies.

Apparent digestibility of amino acids

Apparent digestibility of amino acids is presented in Table 8. Significant ($P<.05$) differences of apparent digestibility were found for the following essential amino acids: arginine, histidine, isoleucine, leucine and phenylalanine. The non-essential amino acids aspartic acid, proline, serine and tyrosine also showed significant treatment differences as did amino acid recovery as a percentage of total protein.

The feature which appears most striking of the data in the present report is the consistent trend for digestibility of amino acids in 00-RSM and C-RSM diets to be lower than other diets and generally to be similar to each other. Digestibility of amino acids in the SBM diet was generally best with intermediate results for the partial replacement of SBM with RSM. In some cases, treatment differences were

Table 8. Apparent digestibility of amino acids

Treatment no.	1	2	3	4	5	Sex		Period		Grand	
Protein source	SBM*	00-RSM	00-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM+
Amino acids %											
Essential											
Arginine	89.4^{a}	86.5^{b}	89.2^{a}	86.4^{b}	86.4^{b}	86.7	86.0	88.2	88.5	86.3	0.71
Histindine	89.2^{a}	86.2^{bc}	88.1^{ab}	85.6^{c}	86.9^{bc}	87.4	87.0	86.6	87.7	87.2	0.68
Isoleucine	82.9^{a}	78.9^{b}	82.7^{a}	78.8^{b}	81.0^{ab}	81.1	80.5	79.8	81.8	80.8	1.03
Leucine	85.3^{ab}	82.4^{c}	87.1^{a}	84.2^{bc}	83.7^{bc}	84.8	84.2	84.5	84.5	84.5	0.80
Lysine	80.3	75.9	79.9	77.4	78.5	79.0	77.8	77.5	79.3	78.4	1.35
Methionine	76.9	77.0	78.5	77.8	77.9	78.0	77.2	76.3	78.9	77.6	1.25
Phenylalanine	85.2^{a}	80.6^{c}	84.2^{a}	81.1^{bc}	82.8^{b}	83.1	82.5	81.9	83.6	82.8	0.80
Threonine	81.7	77.6	81.1	78.2	79.6	79.8	79.4	78.6	80.6	79.6	1.06
Valine	82.3	80.2	82.7	79.4	80.9	81.4	80.8	80.3	81.9	81.1	0.99
Non-essential											
Alanine	76.4	75.4	78.1	75.1	76.0	76.4	76.0	75.7	76.7	76.2	1.41
Aspartic acid	83.8^{a}	77.0^{b}	81.4^{a}	76.4^{b}	80.5^{a}	80.4	79.3	79.0	80.7	79.8	1.07
Cystine	93.3	91.8	93.[illegible]	92.2	93.3	92.9	92.8	93.0	92.7	92.8	0.92
Glutamic acid	91.5	90.0	91.[illegible]	90.2	91.0	91.1	90.6	90.1	91.7	90.9	0.46
Glycine	82.5	80.4	83.0	80.2	81.6	81.8	81.2	80.6	82.4	81.5	0.98
Proline	91.2^{a}	88.7^{ab}	89.2^{a}	86.5^{b}	90.2^{a}	88.6	88.0	88.6	88.1	88.3	0.89
Serine	86.4^{a}	83.5^{ab}	85.6^{a}	82.2^{b}	84.7^{ab}	84.7	84.3	83.5	85.5	84.5	0.96
Tyrosine	76.0^{a}	68.7^{b}	75.2^{a}	68.2^{b}	71.7^{ab}	73.0	71.0	71.4	72.6	72.0	1.56
Recovery of amino acids	80.4^{a}	75.8^{b}	77.6^{ab}	75.6^{b}	78.2^{ab}	76.8	78.2	78.9	76.1	77.5	1.16

* SBM = soybean meal; 00-RSM = rapeseed from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM = commercial rapeseed meal.

+ SEM Standard error of means.

a, b, c Means in the same row with the same letter or no letter are not significantly different at $P<0.05$.

significant and in some cases they were not but it is felt that the consistency of the trend is the most meaningful feature. In all cases where significant differences were observed, the above-mentioned trends were evident. Also, amino acid digestibility of the 00-RSM and C-RSM diets was significantly ($P<.05$) less than the SBM diet in cases where significant differences occurred. It is also obvious that the trends observed in digestibility of amino acids parallel the differences between diets observed for other measures of digestibility.

Significant differences of apparent digestibility for certain essential amino acids appear to be associated with their known interrelationships but this may only be a casual effect not related to treatment differences. For example, the basic amino acids arginine and histidine have significantly ($P<.05$) greater digestibility in the SBM than in 00-RSM or C-RSM diets. Digestibility of these amino acids in the other two diets is intermediate. The branched chain amino acids isoleucine and leucine as well as the phenolic amino acids phenylalanine and tyrosine all show relatively similar significant ($P<.05$) treatment differences, although absolute value of the digestibility coefficients differ for each amino acid. Thus the above-mentioned trends of lowest digestibility values were observed for diets containing 00-RSM and C-RSM and highest

values for those with SBM with the exception of leucine and intermediate values for those with partial substitution of RSM for SBM.

The non-essential amino acids indicate similar trends in digestibility which were evident for essential amino acids. Digestibility of amino acids in 00-RSM and C-RSM diets tended to be lower than SBM, with intermediate results obtained from partial replacement of SBM with either RSM. Significant differences for aspartic acid and tyrosine were similar to the significant differences which occurred for the essential amino acids, with 00-RSM and C-RSM having significantly ($P<.05$) lower digestibilities than the SBM or 00-RSM+SBM diets. Digestibility of proline and serine in the 00-RSM diet was not significantly different from the SBM diet but the digestibility of these amino acids in the C-RSM diet did differ ($P<.05$) from the SBM diet.

Comparison of the amino acid digestibilities in Table 8 with energy and nitrogen digestibility coefficients in Table 7 indicates clearly that these same trends are evident. Digestibility coefficients of energy and nitrogen of the SBM diet were greatest and 00-RSM and C-RSM had lowest digestibilities ($P<.05$). The two diets with mixtures of the protein sources were intermediate for all parameters of digestibility. Since similar differences are apparent for digestibility of amino acids it is clear that overall

digestibility of the diets must be considered in this work and not availability of specific amino acids. The reasons for the overall depression of apparent digestibility of the 00-RSM and C-RSM compared with SBM diets must be considered. The high levels of CF in both sources of RSM in light of the high levels used may account for the reduced digestibility of the 00-RSM and C-RSM diets and will be discussed later in more detail. Recent identification of yellow-seeded varieties of rape which have lower levels of fibre than present varieties, including Tower, should largely overcome the effects of high fibre levels when the yellow-seed characteristic is incorporated into commercial rape production (Stringham et al, 1974).

In general, the digestibilities found in this study appear lower than apparent digestibilities determined by Cho and Bayley (1970). An explanation of the differences may be found in the fact that Cho and Bayley fed semi-purified diets with corn starch and corn sugar as energy sources whereas practical diets using barley and wheat as energy sources were used in the present study.

The amino acids likely to be limiting in diets with SBM and RSM as supplementary protein sources, i.e., lysine and methionine, do not exhibit significant differences due to dietary effects yet the trend to lower digestibility in the RSM diets is present. Also, it is interesting to note that

lysine, methionine and threonine, the amino acids most likely to be limiting in diets based on small grains (Rerat, 1972; Ivan, 1974; Aw-Yong and Beames, 1975), show the lowest digestibilities of all amino acids. Ranking the individual amino acids across the diets show that the same relative differences hold for all amino acids. For example, highest digestibilities were found for arginine in all diets and lowest for lysine in diets containing RSM but lowest for methionine in the SBM diet. The latter results may indicate first-limiting amino acids. Orok et al, (1975) suggested that lysine availability was lower in RSM than in SBM. Sarwar et al, (1975) found that true digestibility of lysine in Span RSM was significantly less than that in SBM for rats. Later work (Sarwar and Bowland, 1976) indicated that both lysine and protein of 00-RSM were well digested in pigs. This latter report indicates that lysine availability of 00-RSM should not be a major problem. Bell (1975) found that methionine may be limiting in RSM since the addition of 0.1% synthetic methionine resulted in an increase of ADG in pigs fed either Bronowski or Span RSM.

In the present work, it appears in Table 5 that sulfur amino acids do not meet the requirements (NAS-NRC, 1973) for 5-10 or 10-20 kg pigs. Also, the lysine level may have been marginal for 5-10 kg pigs. These results may be reflected in the relatively low performance of all pigs in the

starting phase. However, since all diets show similar levels of lysine and methicnine, the dietary levels of these two amino acids do not account for the differences observed in performance. This is particularly the case with the SBM diet, which had the lowest level of sulfur amino acids but highest performance. Cystine values may, however, be underestimated in these determinations because of conversion of cystine to cysteine which occurs to a limited extent during hydrolysis of the sample. Cysteine is not included in the analysis of cystine.

In the present study, digestibility of amino acids appeared to be related to overall digestibility of the diets rather than to particular problems of availability of specific amino acids. Digestibility coefficients of amino acids reflect the same trends observed for energy as well as nitrogen and for live animal perfcrmance. The present report is in agreement with the data of Cho and Bayley (1970) who showed that reduced digestibility of amino acids in diets containing RSM was reflected in a similar reduction of energy and nitrogen digestibility in semi-purified diets.

Diets were formulated to be isocaloric as well as isonitrogenous; thus, the differences in energy and nitrogen digestibility coefficients which did occur for 00-RSM and C-RSM in this experiment were due to differences in digestibility. It appears that some factor in both sources

of RSM caused a depression in digestibility. Two factors considered during the starting phase of this experiment to have been likely causes of decreased performance of pigs fed 00-RSM were a reduction in feed intake and also a high fibre level in both sources of RSM. Numerous authors using various methods of estimating fibre levels have shown that DE decreases with increasing fibre levels in diets of pigs, e.g. Lucas (1949-cited by A.R.C., 1967) using Weende CF methods; Drennan and Maguire (1970) using acid detergent fibre; King and Taverner (1975) using neutral detergent fibre.

Considering that the differences in digestibility were not large, the known effects of high fibre levels would have been most serious in the starting phase which is when the digestibility studies were made. It is probable that high fibre levels of the 00-RSM diet resulting from the very high level of inclusion of 00-RSM, causing a slight depression in digestibility can, in conjunction with the reduced feed intake, account for the differences in performance in the starting phase compared with pigs fed SBM diets. This effect would then be manifested in a reduced F/G, which in fact occurred. The growth depression due to high CF levels decreases as the animal matures and body weight increases (Cunningham et al, 1962), thus in the finishing period, it would be expected that differences between SBM and 00-RSM

diets would be minor. Other factors such as palatability of the RSM could have affected feed intake but it cannot be determined in this trial the effects such factors could have on digestibility. As was discussed previously, the above explanation in regards to CP cannot account for the severe depression which occurred when C-RSM was the sole supplemental protein source. Since both fibre levels and digestibility of 00-RSM and C-RSM diets were similar, it would be expected that fibre levels would therefore have relatively similar importance in both diets. The severe depression of growth in pigs fed C-RSM was attributed to a very inferior F/G in the starting period which could be associated with the glucosinolate levels in the C-RSM.

Carcass studies

Results of the carcass studies are presented in Table 9. No significant differences were found in carcass weight, dressing percentage, length, average and total backfat, lean in ham face or R.O.P. score. Loin areas for pigs fed SBM were significantly ($P<.05$) larger compared with pigs fed 00-RSM and C-RSM diets. Weight of ham also showed significant differences but are virtually the reverse of loin eye area values. Pigs fed 00-RSM, C-RSM and C-RSM+SBM diets had significantly ($P<.05$) greater weight of ham as a percentage of weight of side than pigs fed SBM.

As can be seen in Table 9, the differences in carcass

Table 9. Carcass characteristics

Treatment no.	1	2	3	4	5	Sex		Period		Grand	
Protein source	SBM[≠]	00-RSM	00-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM[+]
Number of pigs	15	16	16	15	16						
Average backfat, cm	2.9	2.9	2.8	2.6	2.8	2.6	2.9***	2.9*	2.7	2.8	0.09
Total backfat, cm	8.6	8.6	8.5	7.7	8.3	7.8	8.8***	8.6*	8.0	8.3	0.27
Loin area, cm^2	30.1[a]	27.0[b]	29.0[ab]	27.2[b]	28.1[ab]	28.9	27.7	28.3	28.3	28.3	0.78
Wt. of ham/wt. of side, %	26.6[b]	27.6[a]	27.2[ab]	27.9[a]	27.6[a]	27.6	27.1	26.7	28.1***	27.4	0.30
Lean in ham face, %	57.8	56.0	56.0	57.5	57.0	58.2*	55.5	54.6	59.1***	56.8	1.14
Carcass weight, kg	65.7	63.3	64.6	61.4	63.5	62.6	64.8*	64.1	63.3	63.7	1.16
Final liveweight, kg	85.4	84.3	85.0	82.1	84.8	82.9	85.7*	84.7	83.9	84.3	1.35
Dressing, %	72.0	75.0	76.3	74.8	74.8	73.6	75.6	75.9	73.3	74.6	2.27
Length, cm	75.0	74.4	74.7	74.0	74.4	74.7	74.3	74.4	74.6	74.5	0.61
ROP score	72.3	71.7	71.8	73.1	72.4	73.1***	71.4	71.4	73.1**	72.3	0.57
ROP score (sex corrected)	72.3	71.7	71.8	73.0	72.5	72.1	72.4	71.4	73.1**	72.3	0.56

[≠] SBM = soybean meal; 00-RSM = rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM = commercial rapeseed meal.

[+] SEM = Standard error of means.

a, b, c Means in the same row with the same letter or no letter are not significantly different at $P<0.05$.

measurements are not large. Lean in ham face reflects the amount of muscle in the ham but may not necessarily be related to total weight of ham. The latter parameter is necessarily the sum of the weights of lean tissue and fat in the ham. The inference cannot be drawn that more of the ham weight in pigs fed the RSM diets was fat even though lean in the ham face was significantly less than pigs fed SBM. Dissection of fat and lean are required to draw such an inference.

Any important differences in carcass fat should be reflected in differences in backfat since this parameter is correlated with carcass fat content (Fredeen et al, 1964; r=0.69 for total backfat vs. % yield of lean cuts). Richmond and Berg (1971) reported similar effects. Backfat thickness in conjunction with carcass weight is the basis of the Canadian Hog Carcass Valuation System (CDA, 1969). It must be appreciated that backfat thickness in this present study is less than usually reported at this station (Bowland, 1974a; Bowland et al, 1975) but pigs were lighter than the usual slaughter weight of 90-92 kg.

Typical sex differences were observed with barrows having significantly thicker backfat ($P<.001$) but gilts having greater ($P<.05$) lean in ham face and R.O.P. score ($P<.001$). The significant difference in the latter parameter is accounted for in the calculation of sex-

corrected R.O.P. score. Thus, no significant sex differences are apparent when the correction is applied. Results are similar to those of Newell and Bowland (1972) and Orok et al (1975).

Backfat measurements were significantly (P<.05) greater in Period 1 than Period 2, but weight of ham/weight of side and lean in ham face were significantly greater (P<.001) in Period 2 than Period 1. Also, R.O.P. scores were significantly (P<.01) greater in Period 2 than in Period 1.

Thyroid hormone levels

Thyroid hormone data are summarized in Table 10. Initially both periods were considered together in a factorial analysis but because of large differences in the mean values for the 2 periods, separate analyses were then made.

In period 1, no significant differences were found for T-4, T-3 RIA or T-7. T-3 uptake was significantly (P<.05) greater for the pigs fed SBM than other diets. However, T-3 RIA and T-3 uptake do not show the same trends, thus evaluation of these results is uncertain.

In period 2, significant differences occurred for T-4, T-3 uptake and T-7, but not for T-3 RIA. T-4 levels approximated performance values in that highest T-4 levels were produced by SBM and lowest by C-RSM (P<.05). Pigs fed

Table 10. Serum thyroid hormone levels at 10 weeks of age

Treatment no.	1	2	3	4	5	Sex		Grand	
Protein source	SBM[≠]	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	mean	SEM[+]
Period 1									
Number of pigs	8	8	8	8	8				
T_4 ug/100 ml	4.2	4.3	4.0	3.8	4.6	4.5	3.9	4.2	0.40
T_3 uptake %	40.5[a]	36.6[b]	36.4[b]	35.1[b]	36.4[b]	36.2	37.7	37.0	0.71
T_3-RIA ng/100 ml	133.2	134.1	128.2	152.4	143.7	136.1	140.5	138.3	11.6
T_7	1.70	1.57	1.45	1.33	1.66	1.62	1.47	1.54	0.16
Period 2									
Number of pigs	8	8	8	8	8				
T_4 ug/100 ml	2.8[a]	2.5[ab]	2.8[a]	1.7[c]	2.1[bc]	2.4	2.4	2.4	0.18
T_3 uptake %	37.9[a]	31.5[c]	32.0[c]	32.1[c]	35.0[b]	33.6	33.8	33.7	0.93
T_3-RIA ng/100 ml	61.1	56.0	70.7	54.0	60.5	60.9	60.0	60.5	10.03
T_7	1.07[a]	0.81[b]	0.89[b]	0.56[c]	0.74[b]	0.81	0.82	0.81	0.06

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

+ S E M Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at $P<0.05$.

C-RSM and C-RSM+SBM had significantly (P<.05) lower T-4 levels than pigs fed SBM diets. No significant differences occurred between 00-RSM, SBM or 50% replacement of SBM by 00-RSM for T-4. T-3 uptake levels were significantly (P<.05) lower for 00-RSM, 00-RSM+SBM and C-RSM diets than for SBM or the C-RSM+SBM diets which was also significantly (P<.05) less than that cf pigs fed the SBM diet. T-3 RIA was not significantly different for any diets. T-7 values were highest for pigs fed SBM and least for pigs fed C-RSM, both of which were significantly (P<.05) different from each other and from the other three diets.

Interpretation cf these results is difficult in that large differences occurred between periods and little information is available on the euthyroid ranges of thyroid hormone levels in blocd or serum of pigs.

Bowland (1975) reported serum T-4 levels of 2.2-3.3 ug/100 ml of plasma for pigs at 8 weeks of age and 2.4-4.5 ug/100 ml for pigs at 14 weeks of age. Lowest levels of T-4 were found in pigs receiving Span RSM. Egbuiwe (1975) reported T-4 values that ranged from 4.5-5.5 ug/100 ml. Onaghise (1976) reported T-4 levels of 1.8-3.5 ug/100 ml for pigs in the growing phase. Aherne et al (1976) reported T-4 ranges of 3.3-3.8 ug/100 ml for 19 kg pigs, 5.0-6.4 ug/100 ml for 87 kg pigs and 4.3-6.1 ug/100 ml for pigs 130 kg. Onaghise (1976) also reported T-3 uptake ranges of 33.9-

40.3% and T-3 RIA of 46-117 ug/100 ml of serum.

The results of T-4 determination in period 1 are greater than those reported by Bowland (1975) or Onaghise (1976) but slightly less than those of Egbuiwe (1975). In period 2, however, T-4 levels were less than those found by Bowland (1975) but T-3 uptake and T-4 levels were similar to those reported by Onaghise (1976). However, T-3 RIA was generally higher in period 1 and lower in period 2 than the values reported by Onaghise (1976) which were determined at the same time and in the same laboratory as the present work.

The important points that can be ascertained from this study of thyroid hormone levels is that an improvement in serum thyroid hormone effects was noted for the pigs fed very high levels of 00-RSM compared with pigs fed C-RSM diets. This confirms other work reported in this thesis that the residual glucosinolates in Tower RSM did not cause major interference with the thyroid metabolism in the pig as did high levels of C-RSM. Thus, the depression of performance of pigs fed 00-RSM which occurred and which was non-significant in most cases compared with pigs fed SBM can then largely be attributed to other factors. In this study these factors appear to be a inferior feed intake and decreased F/G, possibly associated with high CF levels in 00-RSM causing a slight reduction in digestibility. The

thyroid hormone levels found in pigs fed the C-RSM diet although not consistently significantly lower than those of pigs fed other diets, tend to be lower than pigs fed SBM diets. T-4 levels, particularly, reflect these trends and were found in Part 2 of this study to closely agree with other indicators of thyroid status. The results suggest that some inhibition of thyroid function occurred in pigs fed C-RSM. Studies on net synthesis and degradation of thyroid hormones would be required to definitively determine whether thyroid inhibition occurred.

Summary

A total of 80 pigs averaging 5.3 kg in weight at allotment were fed five experimental diets from 4 weeks of age to market weight in two time periods. The objectives of the study were to compare a low-glucosinolate, low erucic acid RSM and commercially available RSM as complete or partial replacements for SBM in starting, growing and finishing diets for pigs.

A partial replacement of SBM by 00-RSM resulted in similar ADF, ADG and F/G even though rather high levels (6.1-11.9%) of 00-RSM were used. Complete substitution of SBM by 00-RSM resulted in some reduction of ADF, ADG and inferior F/G. The difference in body weight gain between SBM and 00-RSM was likely due to reduced feed intake, and to

high fibre levels in the 00-RSM diet which may have caused a lower apparent digestibility of energy, nitrogen and amino acids. This reduced digestibility was associated with an inferior F/G and consequently slower gains of pigs fed 00-RSM ccmpared to pigs fed SBM diets.

ADG and F/G of pigs fed C-RSM was markedly inferior to pigs fed other diets. Feed intake was less than other diets but differed significantly only during the starting phase. Such effects have been attributed to high levels of glucosinolate found in C-RSM. Factors such as high fibre levels and lack of palatability could be expected to contribute in a similar manner in both 00-RSM and C-RSM diets. Performance of pigs fed C-RSM as a partial replacement of SBM was similar to pigs fed 00-RSM diets.

Minor effects of the dietary treatments were observed on carcass characteristics. Greater loin area was observed in pigs fed SBM than in pigs fed diets with complete replacement of SBM by either source of RSM. Pigs fed SBM diets had lowest weight of ham as a percentage of the side.

Determination of the thyroid hormone (T-3, T-4) levels suggested that no major depression of thyroid metabolism occurred from feeding 00-RSM diets. This is consistent with thyroid hormone levels, histological studies and weight of thyroids determined in Part 2 of this study, which showed

that Tower RSM did not cause large adverse effects on thyroid metabolism as did C-RSM diets which inhibited thyroid function.

PART 2. EVALUATION OF DOUBLE-LOW RAPESEED MEAL AS A SOURCE OF PROTEIN FOR YOUNG PIGS: GROWTH, DIGESTIBILITY OF DIETS, THYROID FUNCTION, AND BLOOD SERUM CONSTITUENTS

Introduction

A great deal of nutritional research has been carried out to determine the nutritive value of RSM for pigs. The general conclusion of this work is that depression of ADF, ADG and F/G occurs if pigs are fed diets containing more than 10% RSM during the growing and finishing phase (Manns and Bowland, 1963; Bowland, 1965; Bell, 1965; Bayley et al, 1969; Bowland and Bell, 1972). The main cause of the growth depressing effects of RSM has been attributed to high levels of glucosinolates contained in the meal which results in an inhibition of thyroid metabolism (Bowland, 1965). Numerous species of the Brassica family have been described as goitrogenic for more than 100 years (Greer, 1962). Krusius and Peltola (1966), Lo and Hill (1971b) and Lo and Bell (1972) have demonstrated that the glucosinolates in RSM are capable of causing thyroid hypertrophy and inhibition of thyroid hormonal function. Such effects are known to cause clinical or subclinical hypothyroidism (Kaneko and Cornelius, 1970). The hypothalamic-pituitary control mechanism of thyroid function responds to decreased levels

of circulating thyroid hormones by increasing the secretion of thyroid stimulating hormone (TSH) which causes the thyroid to enlarge. This enlargement or goitre may or may not result in sufficient amounts of thyroid hormone to maintain euthyroid conditions, and thus normal growth, in the presence of an active goitrogen. Diagnosis of this condition can be based on thyroid hormone levels in the plasma, thyroid histology and thyroid weights at necropsy as well as various biochemical tests such as ^{131}I uptake by the thyroid commonly applied in humans. Elevated serum cholesterol and glucose as well as decreased levels of alkaline phosphatase are often seen in cases of hypothyroidism in animals (Mia, 1976).

Development of low-glucosinolate RSM is therefore of primary importance to increasing utilization of RSM. The objectives of this study were to evaluate rate of growth, digestibility of diets, thyroid function and certain blood serum constituents of pigs fed 00-RSM (cultivar Tower) compared with SBM and C-RSM.

Experimental

Animals and diets

Thirty-three crossbred pigs (Lacombe x Yorkshire) were assigned to five experimental diets (Table 11) in an experiment conducted at The University of Alberta Swine

Table 11. Formulation of diets (percentage basis - as fed)

Treatment no.	1	2	3	4	5
Protein source	SBM[≠]	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM
Ingredients					
Wheat	56.2	49.5	53.4	47.4	52.7
Barley	18.7	16.5	17.8	15.8	17.5
Soybean meal (48.0%)	19.1	--	10.9	--	11.4
OO-Rapeseed meal (38.6%)	--	25.5	10.9	--	--
C-Rapeseed meal (33.2%)	--	--	--	28.3	11.4
Animal tallow	1.5	4.0	2.5	4.0	2.5
Iodized salt	0.5	0.5	0.5	0.5	0.5
Limestone (ground)	1.0	1.0	1.0	1.0	1.0
Calcium phosphate	1.5	1.5	1.5	1.5	1.5
Mineral-vitamin premix[e]	1.5	1.5	1.5	1.5	1.5
Composition-determined					
Dry matter %	90.8	91.1	91.1	91.2	91.1
Crude protein %	18.5	18.6	19.1	18.1	18.3
Calculated digestible energy kcal/kg	3167	3213	3187	3219	3187
Crude fibre %	4.5	7.2	5.6	8.1	6.5
Ether extract %	3.5	6.9	4.6	5.7	4.7
Calcium %	0.93	1.02	0.94	1.02	0.96
Phosphorus %	0.75	0.84	0.83	0.87	0.79
Oxazolidinethione mg /g	0	0.22	0.07	0.45	0.55
Isothiocyanates mg /g	0	0	0	0.44	0.64

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

e as in starter diets - Part 1.

Research Unit from January to March, 1975. Pigs were equalized as to weight and sex following weaning at 3 weeks of age and allowed a one week adjustment period during which time the experimental diets were introduced. The experiment was conducted from 4-10 weeks of age after which all pigs were sacrificed for thyroid, liver and muscle studies.

Initially 30 pigs were assigned to this experiment. but a number of pigs died on all treatments during the initial week of the experiment. Deaths were diagnosed[1] as the result of colibaccilosis associated with an outbreak at this station of a virulent E. coli infection. Pigs of similar weight and sex were substituted where possible incuding additional extra female on each treatment giving a total of 33 pigs were used for growth and thyroid studies but because of significant replicate effects, only 28 pigs could be used for serum chemistry studies.

Pigs were housed individually in pens 0.64 x 1.2 m with partially slotted floors. Feed was available ad libitum from self feeders. Water was available free-choice in each pen.

Diets were formulated to be isonitrogenous by replacing an equivalent amount of SBM by RSM and also to be isocaloric

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[1]Dr. D.W. MacDonald, Veterinary Services Branch, Alberta Agriculture, Edmonton, Alberta.

on a DE basis. The diets were based on barley and wheat and, contained 00-RSM, C-RSM, SBM, 00-RSM+SBM, and C-RSM+SBM as in Part 1.

Diets were formulated to provide 18% CP and 3170 kcal DE/kg. Feed consumption and body weight gain were determined on a weekly basis from 4-9 weeks of age.

Digestibility studies

Determinations of digestibility of nitrogen and energy were made in the ninth week of age. Two pigs of each sex were utilized in two replications, with the exception that no male animal was available for the 00-RSM+SBM diet in the first replicate. The total collection method of Castell and Bowland (1968) was followed using 10 metabolism crates in each replicate. Pigs were fed at a level of 90% of the feed consumption of the previous week.

An initial 3-day adjustment period was allowed followed by a 3-day collection of feces and urine. Feces were subsequently dried for 3 days at 60 C in a forced air oven and ground in a laboratory mill. Representative samples of urine were freeze-dried prior to analytical determinations of feed, feces and urine as in Part 1.

Analyses of dry matter, Kjeldahl nitrogen and fibre of diets as well as dry matter and nitrogen of feces and urine were made according to A.O.A.C. (1970) methods. Energy was

determined in an adiabatic oxygen bomb calorimeter.

Carcass studies

At the conclusion of the trial at 10 weeks, all pigs were sacrificed in 2 replicates one week apart and thyroids were removed immediately, weighed and fixed in a 10% buffered formalin for histological studies. A 50-60 g sample of the right lobe of the liver and 10-20 g sample of the longissimus muscle from the area of the twelfth rib on the right side was removed and frozen in liquid nitrogen. Liver and muscle samples were subsequently freeze-dried and then stored at -20 C until required for analysis.

Determinations in duplicate of fat and Kjeldahl nitrogen on the liver and muscle samples were made in series. Crude fat was determined on a previously dried sample and nitrogen was determined on the same dried, defatted sample. Nitrogen and fat were determined according to A.O.A.C. (1970) methods with low boiling point (35-60 C) petroleum ether used as the fat solvent. Samples were refluxed for 8 hours on a Goldfinch fat extraction apparatus.

Histological studies

Sections were cut from the thyroids after 48 hours, fixed and stained with haematoxylin and eosin. A visual

appraisal was made by Dr. R.E. Clugston[1]. A rating was made by assigning 1, 2 or 3 to denote normal, some change and marked change from normal as follows:

follicle size - uniform = 1, some variation in size = 2, marked variation in size = 3.

colloid strain - uniform = 1, moderate variation in staining = 2, severe variation in staining = 3.

colloid amount - adequate = 1, diminished = 2, very diminished = 3.

colloid vacuoles - some = 1, numerous = 2, marked = 3.

follicular epithelium - cuboidal or columnar = 1, hypercellular = 2.

An overall thyroid histological score was calculated by adding 100 to each value and calculating the mean corrected score. Initially an analysis of variance was calculated for each parameter from above, however, no significant differences were found. The overall thyroid histological score thus appeared to be the most appropriate measure and is therefore the parameter reported.

Blood constituents

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[1]Veterinary Services Branch, Alberta Agriculture, Edmonton, Alberta.

All pigs were bled by anterior vena cava puncture (Carle and Dewhirst, 1942) at 6 and 9 weeks of age in 2 replications with one week between each bleeding. At 6 weeks all pigs were bled 4 hours after feeding a meal which was preceded by an overnight fast as in Part 1. At 9 weeks pigs were bled prior to feeding (0 hours) and at 4, 8 and 12 hours after feeding. This series was also preceded by an overnight fast and a meal as in Part 1 and all food which was refused was weighed and recorded. A 15-ml sample of blood was collected, allowed to stand for 20 minutes and centrifuged at 2500 rpm (1.1 g).

A serum chemistry profile was determined by a commercial laboratory[1] using a Technicon SMA 12/60 Autoanalyzer (Technicon Instruments Corporation, Terrytown, New York). Bowland (1975), Egbuiwe (1975) and Perrin (1975) have described the procedures in detail.

At the initial and 4-hour bleedings, determinations were also made at the same laboratory of serum thyroxine (T-4) according to the serum thyroxine radioimmunoassay of Krahn et al (1974). Protein bound iodine (P.B.I.) was determined by the method developed by the Technicon Instruments Corporation, Research Park, Chauncey, New York

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[1]Dr. S. Hanson and Associates. Medical Laboratory, Edmonton, Alberta.

(Technicon Instruction Manual No. PB/0-1).

Statistical methods

Multi-way analyses of variance (ANOVA) were computed using the method of un-weighted means outlined by Bancroft (1968). This was necessitated because of the unequal number of pigs within treatments and sexes. The error term is obtained in this procedure by adjustment of the mean square derived from a one-way analysis of variance for each parameter based on the harmonic mean:

Adjusted mean square $\frac{1}{}$ x one-way error mean square (Bancroft, 1970).

Treatment means were compared using Duncan's Multiple Range Test (Steele and Torrie, 1960) which was preceded by a significant F-test (Waldo, 1976). A probability of 0.05 was selected as the point of significance between means. The sources of variation were 5 diets and 2 sexes. All sources of variation except replicate and animals were considered as fixed. Notations used to indicate level of significance are: *(P<0.05), **(P<0.01), ***(P<.001). Means not significantly different bear the same superscript or no

superscript.

Results and Discussion

The results will be considered in the order of live animal performance from 4-9 weeks of age, fat and protein determination of carcass liver and muscle, digestibility of diets, thyroid function and blood constituents.

Live animal performance

Body weight at commencement of the trial averaged 5.6 kg (Table 12). Significant ($P<.05$) sex differences in weight were evident at commencement of the trial at 4 weeks of age with females averaging 5.1 kg and males 6.0 kg.

At 9 weeks of age, no significant treatment differences were apparent although mean body weights as indicated in Table 12 differed considerably. Notable animal-to-animal variation in body weights at 9 weeks was observed in this trial (8.2-23.7 kg) and this large variation has been attributed to the disease problem in the early part of the experiment as mentioned earlier. Although pigs on all treatments were affected, those animals on the 00-RSM+SBM diet (Treatment 3) appeared to be affected most and 3 pigs died. The means of the data are based on 7 pigs (3 males, 4 females) per treatment except treatment 3 which had 5 pigs. These means are indicative of the performance achieved on

Table 12. Influence of diets and sex on food consumption, body weight gain and feed : gain ratio

Treatment no.	1	2	3	4	5	Sex		Grand	
Protein source	SBM[≠]	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	mean	SEM[+]
Number of pigs	7	7	5	7	7				
Initial wt. kg	5.4	5.4	5.7	5.3	6.0	5.1	6.0*	5.6	0.30
9 week wt. kg	18.4	15.6	15.5	12.1	17.3	14.3	17.3	15.8	0.91
Average daily feed consumption kg	0.84	0.68	0.77	0.56	0.77	0.67	0.77	0.72	0.04
Average daily gain kg	0.38[a]	0.30[b]	0.28[b]	0.20[c]	0.32[ab]	.26	.33	.29	.02
Feed/gain	2.22	2.29	2.98	2.89	2.45	2.73	2.41	2.56	0.13

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

\+ S E M = Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at P<0.05.

the different diets.

ADF was not significantly different for the 5 diets. However, a definite trend was noticed for pigs fed C-RSM diets to consume less feed than other pigs. Pigs fed 00-RSM tended to consume somewhat less than pigs fed SBM. Consumption of diets with 50% of the SBM replaced by 00-RSM or C-RSM was intermediate between SBM and 00-RSM diets, but differences were not significant.

Average daily gain showed that gain of pigs fed SBM was superior to other diets, and was significantly ($P<.05$) greater than pigs fed the 00-RSM or 00-RSM+SBM diets while ADG of pigs fed the C-RSM diet was significantly ($P<.05$) less than pigs fed other diets. ADG of pigs on the C-RSM+SBM diet was intermediate between SBM and the two diets with 00-RSM and was not significantly different from either.

F/G reflected ADG and ADF inversely but differences were not significant. Lack of significant differences may be an effect of the variability of results as seen in the large standard error. However conversion of the 00-RSM+SBM diet into body weight gain appeared to be markedly inferior compared with pigs fed SBM or 00-RSM diets. This treatment included one pig which gained only 3.9 kg during the 35 days of the experiment. Although this was the lowest gain of any pig in the experiment, it was not removed because certain

other animals in other treatments performed similarly. It was thus not possible to make a subjective decision to remove some animals from some treatments and not other animals. Since the 00-RSM+SBM contained considerable amounts of SBM as did the C-RSM+SBM diet, it would be expected that F/G would be at least as good, if not better than pigs on C-RSM+SBM diet consuming the high glucosinolate RSM used as the source of C-RSM. In Part 1, performance of pigs fed the 00-RSM+SBM diet was not significantly different from pigs fed the SBM diet. It is probable that the colibacillosis syndrome occurring in the early part of the trial contributed to the unfavourable response of pigs fed the 00-RSM+SBM diet. Dunne and Bennett (1970) have indicated that the intestinal wall may be thickened in pigs surviving colibacillosis. This condition may then result in reduced nutrient absorptive capacity and a reduction in the rate of growth for a variable period of time or permanantly. Although this condition occurred across all treatments it may have had a more severe effect in pigs on the 00-RSM+SBM diet. Also, the condition occurred in the first 10 days of the trial and the affected pigs may have recovered in the latter stages of the experiment. Inspection of the weekly body weight records indicated that growth in the last 3 weeks of the trial was very rapid. ADG of pigs in this trial was inferior to the results of Bowland (1975) in a trial designed to study the use of 00-RSM for young pigs.

However, ADF was also lower in the present experiment which may account for the lower rate of growth compared with the work of Bowland (1975) and Bowland et al (1975). Performance of pigs in this present study appeared similar to the starting phase in Part 1, with the exception of pigs fed the 00-RSM+SBM diet.

Work reported in Part 1 of this thesis using a large number of pigs showed that ADF, ADG and F/G of pigs fed isonitrogenous combinations of 00-RSM and SBM were similar to that of pigs fed SBM. A non-significant but consistent trend was, however, noted toward slightly lower ADF, ADG and F/G during the starting period as well as to market by the partial replacement of SBM by 00-RSM. Moody et al (1976) and Castell (1976) also using partial replacement of SBM by Tower RSM showed that performance of pigs fed RSM from Tower rapeseed was not significantly different but consistently slightly less than pigs fed SBM diets. Thus, it can be concluded that performance of pigs on the 00-RSM+SBM in the present experiment was abnormal.

Although differential results of live animal performance are not as clearly evident in this trial as in Part 1, the main effects are discernable. ADF, ADG and F/G of pigs fed the 00-RSM diet was numerically superior compared with pigs fed C-RSM, although significant differences were obtained only for ADG. However,

performance of pigs fed diets with 00-RSM completely replacing SBM was not equivalent to those receiving the SBM diet in terms of ADF or ADG although F/G was similar in this experiment. No significant sex or replicate effects were noted at 9 weeks of age.

Digestibility of diets

The determination of the digestibility of the diets are summarized in Table 13. No significant effects of dietary treatments were observed for any of the parameters measured. However, trends for the digestibility coefficients for nitrogen and energy indicate treatment differences similar to those obtained in the digestibility trial in Part 1. Digestion coefficients for both sources of RSM are numerically less than SBM both for energy and nitrogen in the present trial but were not significantly different as in Part 1.

The apparent trend toward lowered F/G of the C-RSM diet is not evident in reduced digestibility of pigs fed C-RSM. The lower performance of pigs on the 00-RSM+SBM diet (ADG=0.28 kg) vs (0.38 on SBM) is also not reflected in the digestibility ratios and may be accounted for by the fact that the digestibility trials were run in the ninth week of age. The pigs from this treatment which were included in the digestibility study may not have been severely affected by the colibaccillosis condition mentioned previously or may

Table 13. Digestibility and retention data for energy and nitrogen

Treatment no.	1	2	3	4	5	Sex		Grand	
Protein source	SBM≠	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	mean	SEM+
Number of pigs	4	4	3	4	4				
Average body wt. kg	16.5	14.4	15.3	11.9	16.4	13.8	16.1	14.9	1.70
Digestible energy %	82.3	80.4	81.1	82.0	81.5	82.5*	80.4	81.5	1.00
Metabolizable energy %	80.0	77.8	78.7	78.7	78.9	79.9*	77.8	78.8	1.03
ME/DE %	97.0	97.1	96.2	96.0	97.0	96.6	96.8	96.7	0.31
Digestible nitrogen %	82.5	79.5	81.4	81.7	81.0	82.1	80.3	81.2	0.31
N retained/DN %	56.3	61.5	57.5	55.2	60.3	57.9	58.5	58.2	4.80
N retained/N intake %	46.2	49.2	46.7	45.1	48.9	47.5	47.0	81.3	0.09
DE/kg diet kcal	3290	3376	3284	3446	3280	3377*	3293	3335	40.86
ME/kg diet kcal	3198	3280	3183	3308	3182	3271	3189	3230	42.27
DN/kg diet g	23.9	23.7	24.9	23.7	23.9	24.1	23.8	24.0	0.36

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

+ S E M Standard error of means.

have recovered by this time.

Significant (P<.05) sex effects were noted for DE and ME digestibility coefficients and DE/kg of diet. However in Part 1 of this work the digestibility of energy by females was not different from that of males. Also, nitrogen retention data were not significantly different in the present experiment but were in Part 1. Other workers have also shown variable sex effects. Orok et al (1975) found that nitrogen retention was significantly (P<.05) better in gilts than barrows but Bowland (1974a) indicated that sex effects on digestibility may be variable.

Carcass liver and muscle determinations

Results of liver and muscle fat and protein determinations are presented in Table 14. Such determinations are commonly carried out in poultry studies with RSM (Olomu, 1974) and give an estimate of carcass composition in young pigs.

No significant treatment effects were noted for liver dry matter, fat, protein on a defatted basis nor for muscle dry matter, fat or protein. However, standard errors for liver and muscle fat are large and are likely associated with inclusion of variable amounts of fat with the sample.

Liver protein on a dry matter basis was significantly (P<.05) less in pigs fed the C-RSM diet than pigs fed other

Table 14. Fat and protein determination of liver and muscle (percentage basis)

Treatment no.	1	2	3	4	5	Sex		Replication		Grand	
Protein source	SBM[≠]	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM[+]
Number of pigs	7	7	5	7	7						
Liver DM[◆]	96.3	96.3	96.1	96.4	96.1	96.2	96.2	96.1	96.3	96.2	1.72
Liver fat (DM basis)	5.6	5.4	4.7	4.9	4.9	4.8	5.4	4.8	5.4	5.1	0.52
Liver protein (DM basis)	64.7[a]	61.9[a]	60.8[a]	55.4[b]	61.9[a]	61.0	60.9	61.1	60.8	60.9	1.49
Liver protein (DM+ defatted basis)	68.5	65.4	63.9	58.3	63.5	64.2	63.7	64.2	63.7	64.0	1.73
Muscle DM	97.0	96.8	97.4	97.4	96.6	96.8	97.3	97.1	96.9	97.0	0.28
Muscle fat (DM basis)	12.3	10.8	5.7	8.4	11.0	8.7	10.6	7.7	11.6**	9.7	1.67
Muscle protein (DM basis)	78.6	78.5	82.9	80.9	79.2	80.7	79.7	81.6	78.5	80.0	1.72
Muscle protein (DM + defatted basis)	89.7	88.0	87.9	88.3	88.9	88.0	89.2	88.4	88.8	88.6	0.77

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

+ SEM = Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at $P<.05$.

◆ Dry matter.

diets. However, standard errors for liver and muscle fat are large and are likely associated with inclusion of variable amounts of fat with the samples. diets. This effect may be due to the fact that pigs fed C-RSM diet were much lighter at the end of the trial. However, liver dry matter, fat and protein on a dry defatted basis are not significantly different. Fat and protein levels were higher in muscle than in liver although the dry matter contents were similar.

Sex effects for liver and muscle dry matter, fat and protein were not significantly different at the time these pigs were killed.

A significant ($P<.01$) difference for replicates was observed for fat content of muscle tissue. A value of 7.7% was obtained in replicate 1 and 11.5% in replicate 2. Inspection of the data indicates that considerable variability existed for this parameter. Although superficial fat and connective tissue were removed, the possibility exists that a variable amount of fat deposited in the muscle was included in the sample taken from the longissimus muscle. Data for fat in the liver are much more uniform which may be a result of taking a larger size of sample, thus any anomaly in sampling would not have such a large influence on the results as in the case for muscle samples.

Although significant treatment differences for liver and muscle protein were noted only for liver protein on a dry matter basis, similar but non-significant trends were noted for liver and muscle protein on a dry, defatted basis. These differences may be related to weight of pigs at the end of the trial. It may be anticipated in young very actively growing animals such as these pigs, that increases of protein would occur very rapidly leading to greater protein content with increasing body weight. Richmond et al (1970) and Richmond and Berg (1971) also found that body protein levels increased with weight in the weight range of pigs in this study.

Assessment of thyroid function

Thyroid hormone levels and thyroid histology data are presented in Table 15. Final body weight at 10 weeks of age showed similar trends of treatment response to the 9 week weights. Pigs on SBM diets were heaviest and those on the C-RSM diet were lightest at the end of the trial, but differences were not significant although numerically large.

Thyroid weights show that pigs on the C-RSM+SBM diet had thyroids which were significantly ($P<.05$) heavier than other pigs. Pigs on the C-RSM diet tended to have thyroids which were intermediate between pigs fed C-RSM+SBM and the pigs on SBM or 00-RSM diets. These differences were not

Table 15. Thyroid weights and histology

Treatment no.	1	2	3	4	5	Sex		Grand	
Protein source	SBM[≠]	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	mean	SEM[+]
Number of pigs	7	7	5	7	7				
Final body weight kg	21.3[b]	17.3[b]	15.0[b]	12.9[b]	18.7[a]	16.3	17.8	17.3	1.17
Thyroid wt. g	3.1[b]	3.7[b]	3.3[b]	4.0[b]	6.6[a]	3.4	4.9*	4.1	0.36
Thyroid wt./final body wt. g /kg	0.14[c]	0.21[b]	0.19[b]	0.30[a]	0.33[a]	0.22	0.25	0.24	0.01
Corrected overall histological score	122	137	144	119	128	131	129	130	8.15
Protein bound iodine									
- 6 weeks ug/100 ml	5.5	6.3	3.1	5.4	4.4	3.9	5.9	4.9	0.88
- 9 weeks ug/100 ml	5.4	4.8	5.1	3.9	6.1	5.4	4.7	5.0	1.32
Thyroxine									
- 6 weeks ug/100 ml	4.4[a]	2.7[b]	2.8[a]	2.4[b]	2.5[b]	3.7*	2.2	3.0	.40
- 9 weeks ug/100 ml	6.0[a]	4.2[b]	5.7[a]	3.5[b]	3.9[b]	4.4	4.9	4.7	.31

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meals.

+ S E M = Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at $P<0.05$.

statistically significant.

Calculation of thyroid weight as a function of body weight removed some of the obvious relationships between body weight and thyroid weight. As a result, thyroid hypertrophy is apparent in pigs fed both C-RSM and C-RSM+SBM ($P<.05$) compared with pigs fed the other 3 diets. These findings are in agreement with those of Sihombing et al (1974) who showed that goitrogens including 0.5% potassium thiocyanate resulted in thyroid weight/body weight values of 0.17 vs 0.42 for diets with and without 0.2 ppm of iodine. Feeding 0.075% Tapazole (1-methyl-2-mercaptoimidazole) resulted in similar thyroid weight/body weight values of 0.18 and 0.34 in diets with and without 0.2 ppm of iodine. The iodine levels provided in the diets in the present experiment exceeded the NAS-NRC (1973) recommended requirement of 0.2 ppm, which was found in the study of Sihombing et al (1974) to permit normal thyroid function. In the present experiment, evidence of hypertrophy occurred in the presence of adequate iodine in both C-RSM diets containing high levels of glucosinolates. In the report of Sihombing et al (1974), the reduction in the weight gains due to presence of goitrogen in the feed was attributed to decreases in food intake. In the present experiment thyroid weight/body weight was also significantly ($P<.05$) greater for pigs fed both 00-RSM diets than those fed the SBM diet.

These weights were significantly (P<.05) less for both 00-RSM diets than for pigs fed either C-RSM diet indicating that C-RSM had a greater hypertrophic effect on the thyroid than did 00-RSM.

P.B.I. was not significantly different between diets at 6 or 9 weeks of age, although at 9 weeks P.B.I. values were numerically less for pigs fed C-RSM diets than for other pigs. Sex effects were variable. No clear evidence was found of a difference at 6 weeks compared with 9 weeks. Manns and Bowland (1963) obtained average P.B.I. values of 3.1-5.3 ug/100 ml of serum in market pigs with values of 5.3 ug/100 ml for pigs receiving 50 to 100% of RSM as the supplementary protein source. Kaneko and Cornelius (1970) reported P.B.I. values of 2.7 for Landrace pigs and 4.4 for Large Whites. Bowland (1975) reported average P.B.I. values of 8.6 ug/100 ml. In the studies by Bowland differences in P.B.I. levels were not significant between bleeding at 8 or 14 weeks of age. Egbuiwe (1975) reported P.B.I. ranges of 4.2-6.1 ug/100 ml for pigs of approximately 40 kg body weight. Aherne et al (1976) found P.B.I. values of 7 week old pigs ranged from 3.8-4.2 ug/100 ml of serum, at 87 kg ranged from 4.0-5.2 ug/100 ml and at 130 kg ranged from 3.1-5.3 ug/100 ml. It is evident that P.B.I. values at 6 and 9 weeks found in this study are within the apparently normal range in pigs.

T-4 levels were not significantly different at 6 weeks of age but at 9 weeks, serum T-4 levels were significantly ($P<.05$) reduced for both diets containing C-RSM and also by the 00-RSM diet. Levels of T-4 apparently increased from 6 to 9 weeks of age but it is not possible to determine whether this is an age or a weight-related phenomenon in the present study and was not tested statistically.

Interpretation of the results of P.B.I. and T-4 tests in light of the normal range in the literature cited above and in Part 1 of this study indicates a normal range of 2.2-10.5 ug/100 ml of serum for T-4 (Bowland, 1975; Egbuiwe, 1975; Aherne, 1976; Onaghise, 1976) and 3.1-8.6 ug/100 ml for P.B.I. In the present study however, thyroid weight as a function of body weight at 9 weeks showed a clear relationship tc an apparent hypertrophic condition of the thyroids of pigs fed C-RSM or C-RSM+SBM diets.

T-4 at 9 weeks of age of the pigs fed the 00-RSM diet was significantly ($P<.05$) less and thyroid weight/body weight was greater ($P<.05$) than for pigs fed the SBM diet. These effects did not appear as severe as in pigs fed either diet with C-RSM. Considering the work of Krusius and Peltola (1966), Lo and Hill (1971b) and Lo and Bell (1972) that sufficient residual glucosinolate remained in Bronowski RSM to interfere with release of thyroid hormones or cause

thyroid hypertrophy in rats, the effects of the 00-RSM diet on thyroid function found in this experiment cannot be unexpected. This factor is particularly relevant in consideration of the high levels of supplementation in the 00-RSM diet.

Sufficient goitrogen was present in both the C-RSM and C-RSM+SBM diets to cause thyroid enlargement and to produce a significant ($P<.05$) reduction in T-4 level. However, T-4 levels in this experiment, including the values for the pigs fed the C-RSM diet, are within the normal range found in the previous trial reported in Part 1 (period 1:4.1-4.6 ug/100 ml; Period 2:2.1-2.8 ug/100 ml) and also within the apparently normal ranges for pigs (2.2-10.5 ug/100 ml) found by several other workers cited in Part 1 of this thesis.

No significant differences between treatments were found in the histological data. Although a visual microscopic assessment was made, no consistent indications could be found of major cellular disfunction. The glands were chosen randomly for examination. These results indicate that massive changes did not occur at the cellular level in pigs fed C-RSM diets but do not rule out the possibility of some degree of impairment of thyroid function.

It is evident that a major problem occurred in

utilization of high levels of C-RSM as evidenced by the inferior ADF, ADG and F/G of pigs fed this meal. However, the levels of C-RSM fed are considerably in excess of the currently recommended levels of RSM for pigs (Bowland and Bell, 1972) and in excess of the level of high glucosinolate RSM shown experimentally to result in significant reductions of ADF, ADG and F/G (Bowland, 1965).

Serum chemistry analyses

Serum analyses are reported in Tables 16a-e for all pigs in this study. An initial bleeding was made at 6 weeks followed by a series of 4 bleedings at 9 weeks of age after an overnight fast. Bleedings at 9 weeks were made prior to feeding (0-hours) and at 4, 8 and 12 hours after ingestion of a meal of the appropriate diet.

Considerable animal to animal variation was observed for the blood constituents as evidenced by the large standard errors of the means. Also, hemolysis was observed in a number of samples after centrifugation. As a result, some enzyme values may have been abnormally high since certain transaminases and particularly lactic dehydrogenase (LDH) from the rupture of red blood cells may lead to serious test errors (Freedland and Kramer, 1970). However, Finlay et al (1969) found only minor effects on constituents in serum, presumably of human origin, in which hemolysis occurred. Also the levels of alkaline phosphatase, LDH and

Table 16a. Serum chemistry analysis - initial bleeding - 6 weeks of age

Treatment no.	1	2	3	4	5	Sex		Grand	
Protein source	SBM≠	00-RSM	00-RSM+SBM	C-RSM	C-RSM+SBM	F	M	mean	SEM+
Number of pigs	6	6	4	6	6				
Body wt. bleeding kg	8.0	7.9	7.8	6.9	8.8	7.1	8.8	7.9	0.47
Calcium mg /100 ml	10.8	10.5	11.0	10.7	11.0	10.8	10.8	10.8	0.17
Phosphorus mg /100 ml	9.9	10.0	9.6	10.0	9.4	9.3	10.2	9.8	0.28
Glucose mg /100 ml	111	112	122	95	108	114	105	109	5.09
Urea nitrogen mg /100 ml	15.2	17.4	16.4	13.8	14.7	15.8	15.2	15.5	0.69
Uric acid mg /100 ml	0.80	0.84	0.81	0.82	0.84	0.80	0.85	0.83	0.05
Cholesterol mg /100 ml	112	116	112	122	114	116	114	115	3.13
Total protein g /100 ml	4.9	4.9	4.9	5.2	5.1	5.0	5.0	5.0	0.09
Albumin g /100 ml	3.0	3.1	3.1	3.1	3.2	3.1	3.1	3.1	0.07
Total bilirubin mg /100 ml	0.30	0.39	0.30	0.45	0.29	0.37	0.32	0.35	0.04
Alkaline phosphatase° mu/ml	294	233	245	213	200	234	240	237	14.79
LDH° mu/ml	566	557	427	546	481	533	498	515	36.86
SGOT° mu/ml	129	150	91	107	98	113	116	115	12.00

≠ SBM= soybean meal; 00-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed.

+ SEM= Standard error of means.

° The units of measurement and methods of determination for alkaline phosphatase lactate dehydrogenase (LDH) and serum glutamic oxaloacetic transaminase (SGOT) were as described by Morgenstern et al (1965), Hochella and Weinhouse (1965) and Morgenstern et al (1966) respectively.

Table 16b. Serum chemistry analysis - 0-hours - 9 weeks of age

Treatment no.	1	2	3	4	5	Sex		Replication		Grand	
Protein source	SBM[≠]	00-RSM	00-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM[+]
Number of pigs	6	6	4	6	6						
Body wt. bleeding	17.1	14.0	14.2	11.7	15.1	12.5	16.4*	15.3	13.6	14.4	1.52
Feed consumed at bleeding kg	0.53	0.46	0.48	0.36	0.42	0.36	0.53**	0.42	0.47	0.4	0.04
N. consumed at bleeding g	15.4	13.6	14.7	10.3	12.3	10.7	15.8	12.5	14.0	13.3	2.92
D E consumed at bleeding kcal	1747	1540	1581	1227	1373	1207	1781	1418	1570	1494	329
Calcium mg /100 ml	11.0	11.2	11.9	10.9	11.0	11.1	11.3	11.3	11.1	11.2	0.31
Phosphorus mg /100 ml	9.9	9.8	9.5	9.8	10.3	9.6	10.2*	10.4**	9.3	9.9	0.19
Glucose mg /100 ml	85[c]	98[a]	99[a]	90[bc]	95[ab]	92.0	95	92	95	93	2.45
Urea nitrogen mg /100 ml	12.6	15.5	9.5	9.4	9.4	12.2	10.3	12.2	10.3	11.3	4.38
Uric acid mg /100 ml	0.29	0.30	0.35	0.29	0.30	0.29	0.31	0.19	0.41**	0.30	0.02
Cholesterol mg /100 ml	122[c]	132[bc]	127[bc]	146[a]	138[ab]	129	137	124	142**	133	3.74
Total protein g /100 ml	5.9	5.6	6.2	5.9	5.8	5.7	6.0	6.1*	5.6	5.9	0.21
Albumin g /100 ml	3.8	3.5	4.0	3.7	3.6	3.6	3.9	4.0*	3.4	3.7	0.19
Total bilirubin mg %	0.43	0.35	0.34	0.48	0.31	0.35	0.42	0.35	0.41	0.38	0.05
Alkaline phosphatase[o] mu/ml	292[a]	227[b]	256[ab]	232[b]	228[b]	241	253	268*	227	247	16.85
LDH[o] mu/ml	427	465	481	572	526	461	528	566	422	494	64.58
SGOT[o] mu/ml	75[b]	87[ab]	74[b]	129[a]	120[a]	84	111	100	94	97	12.96

≠ SBM= soybean meal; 00-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid) C-RSM= commercial rapeseed meal.

+ SEM= Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at P<.05.

o See footnote [o], Table 16a.

Table 16c. Serum chemistry analysis 3 4-hours - 9 weeks of age

Treatment no.	1	2	3	4	5	Sex		Replication		Grand	
Protein source	SBM≠	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM+
Number of pigs	6	6	4	6	6						
Calcium mg /100 ml	11.0	10.8	11.3	10.7	10.9	10.9	11.0	10.8	11.1	10.9	0.35
Phosphorus mg /100 ml	9.3	9.1	9.1	9.2	9.7	9.0	9.5	9.5	9.1	9.3	0.36
Glucose mg /100 ml	137	150	135	131	129	131	142	132	141	136	7.04
Urea nitrogen mg /100 ml	19.5	18.0	24.5	16.9	16.0	20.1	17.8	19.1	18.8	19.0	5.99
Uric acid mg /100 ml	0.26	0.31	0.30	0.34	0.29	0.27	0.33*	0.16	0.43**	0.3	0.02
Cholesterol mg /100 ml	125[b]	138[a]	118[b]	138[a]	136[a]	132	130	125	137**	131	3.25
Total protein g /100 ml	5.6	5.5	5.8	5.4	5.6	5.5	5.6	5.9*	5.3	5.6	0.18
Albumin g /100 ml	3.8	3.5	3.9	3.4	3.6	3.6	3.7	4.0**	3.3	3.7	0.16
Total bilirubin mg /100 ml	0.21	0.30	0.27	0.31	0.27	0.27	0.27	0.28	0.26	0.2	0.04
Alkaline phosphatase° mu/ml	259	219	244	216	217	227	235	251*	212	231	12.20
LDH° mu/ml	556	595	670	628	630	602	631	788**	444	616	79.90
SGOT° mu/ml	97	129	129	201	145	131	150	184*	97	140	31.17

≠ SBM= soybean meal, OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

+ SEM= Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at P<.05.

° See footnote °, Table 16a.

Table 16d. Serum chemistry analysis - 8-hours - 9 weeks of age

Treatment no.	1	2	3	4	5	Sex		Replication		Grand	
Protein source	SBM[≠]	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM[+]
Number of pigs	6	6	4	6	6						
Calcium mg /100 ml	10.9	11.0	10.5	10.4	10.8	10.6	10.9	10.5*	11.0	10.7	0.26
Phosphorus mg /100 ml	9.6	9.6	9.3	9.9	8.9	9.5	9.4	9.7	9.2	9.5	0.72
Glucose mg /100 ml	134[ab]	106[b]	159[a]	113[b]	112[b]	124	126	138*	112	124	9.80
Urea nitrogen mg /100 ml	16.2	15.7	13.6	14.5	13.5	13.9	15.4	14.4	13.9	14.7	1.00
Uric acid mg /100 ml	0.29[bc]	0.35[ab]	0.35[ab]	0.36[a]	0.26[c]	0.32	0.32	0.20	0.44**	0.3	0.02
Cholesterol mg /100 ml	127	128	122	130	127	127	126	122	132*	126	3.29
Total protein g /100 ml	5.8	5.5	5.7	5.5	5.5	5.6	5.6	5.8*	5.4	5.6	0.19
Albumin g /100 ml	3.9	3.6	3.9	3.4	3.6	3.7	3.8	4.1*	3.3	3.7	0.17
Total bilirubin mg /100 ml	0.30	0.29	0.50	0.33	0.28	0.36	0.32	0.36	0.32	0.3	0.05
Alkaline phosphatase mu/ml	247	210	215	207	207	216	219	236*	198	217	13.10
LDH[o] mu/ml	734	564	773	877	596	734	684	913*	505	709	129.50
SGOT[o] mu/ml	205	126	235	405	131	195	246	323**	118	220	59.13

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid) C-RSM= commercial rapeseed meal.

+ SEM= Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at P<.05.

o See footnote [o], Table 16a.

Table 16e. Serum chemistry analysis - 12-hours - 9 weeks of age

Treatment no.	1	2	3	4	5	Sex		Replication		Grand	
Protein source	SBM[≠]	00-RSM	00-RSM+SBM	C-RSM	C-RSM+SBM	F	M	1	2	mean	SEM[+]
Number of pigs	6	6	4	6	6						
Calcium mg /100 ml	10.4	10.6	9.8	10.2	10.5	10.3	10.3	10.0**	10.6	10.3	0.27
Phosphorus mg /100 ml	10.0	9.4	10.1	9.6	9.6	9.7	9.8	10.3**	9.2	9.7	0.25
Glucose mg /100 ml	145[a]	111[b]	136[a]	110[b]	112[b]	127	118	120	125	122	6.93
Urea nitrogen mg /100 ml	12.0	11.7	10.6	10.4	9.7	10.4	11.3	11.3	10.5	10.9	0.78
Uric acid mg /100 ml	0.29	0.27	0.34	0.29	0.30	0.31	0.28	0.15	0.44**	0.3	0.02
Cholesterol mg /100 ml	128	119	137	129	129	132	125	127	130	128	5.21
Total protein g /100 ml	5.9[ab]	5.3[c]	5.9[a]	5.4[c]	5.5[bc]	5.7	5.6	5.8	5.4	5.6	0.18
Albumin g /100 ml	4.1[ab]	3.5[c]	4.2[a]	3.5[c]	3.6[bc]	3.8	3.8	4.2**	3.4	3.8	0.15
Total bilirubin mg /100 ml	0.49[b]	0.30[b]	0.78[a]	0.42[b]	0.29[b]	0.46	0.46	0.48**	0.44	0.46	0.06
Alkaline phosphatase[o] mu/ml	230	195	228	196	204	214	208	232**	189	210	12.28
LDH[o] mu/ml	828[ab]	586[b]	1127[a]	902[ab]	626[b]	788	840	1004**	624	814	111.92
SGOT[o] mu/ml	186[b]	129[b]	501[a]	415[a]	191[b]	238	331	415**	154	284	60.56

≠ SBM= soybean meal; 00-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

+ SEM= Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at $P<.05$.

o See footnote [o], Table 16a.

Table 16f. Serum chemistry analyses - Overall bleeding times

Time of Bleeding	Initial	0-hours	4-hours	8-hours	12-hours	Grand mean	S E M +
Number of pigs	28	28	28	28	28		
Calcium mg /100 ml	10.6^{bc}	11.2^{a}	10.9^{ab}	10.7^{bc}	10.3^{c}	10.7	0.13
Phosphorus mg /100 ml	9.8^{c}	9.9^{a}	9.3^{d}	9.5^{b}	9.7^{b}	9.6	0.10
Glucose gm /100 ml	103^{c}	93^{d}	136^{a}	125^{b}	123^{b}	116	2.96
Urea nitrogen mg /100 ml	15.7^{a}	11.3^{b}	19.0^{a}	14.7^{a}	10.9^{c}	14.3	1.64
Uric acid mg /100 ml	0.87^{a}	0.30^{b}	0.30^{b}	0.32^{b}	0.30^{b}	0.42	0.01
Cholesterol mg / 100 ml	112^{c}	133^{a}	131^{ab}	127^{b}	129^{ab}	126	1.45
Total protein g /100 ml	5.0^{c}	5.9^{a}	5.6^{b}	5.6^{b}	5.6^{b}	5.5	0.08
Albumin g /100 ml	3.1^{b}	3.7^{a}	3.7^{a}	3.7^{a}	3.8^{a}	3.6	0.68
Total bilirubim mg /100 ml	0.34^{bc}	0.38^{b}	0.27^{c}	0.34^{bc}	0.45^{a}	0.36	0.23
Alkaline phosphatase° mu/ml	217^{b}	247^{a}	231^{ab}	217^{b}	211^{b}	225	6.60
LDH° mu/ml	507^{c}	494^{c}	616^{bc}	709^{ab}	814^{a}	628	38.25
SGOT° mu/ml	109^{c}	97^{c}	140^{c}	220^{b}	284^{a}	170	15.70

+ SEM= Standard error of means.

a,b,c,d Means in the same row with the same letter or no letter are not significantly different at P<.05.

° See footnote °, Table 16a.

serum glutamic oxaloacetic transaminase (SGOT) were not seriously altered in the latter study.

No significant differences in serum constituents were noted at 6 weeks of age. At the 0-hour bleeding prior to feeding at 9 weeks, significant ($P<.05$) differences between diets were noted for the following parameters: glucose, cholesterol, alkaline phosphatase and SGOT. The pigs fed the C-RSM diet showed significantly ($P<.05$) higher levels for cholesterol and SGOT than pigs fed the SBM diet. Blood glucose was significantly ($P<.05$) higher for pigs fed 00-RSM and 00-RSM+SBM than pigs fed the SBM or C-RSM diets. Alkaline phosphatase levels of pigs on the SBM diet were significantly ($P<.05$) higher than those of pigs fed the 00-RSM, C-RSM or C-RSM+SBM diets. Values of the above parameters for pigs fed the C-RSM+SBM diet tended to be intermediate. Elevated serum cholesterol and glucose and decreased alkaline phosphatase are typically found in cases of hypothyroidism in animals (Mia, 1976). Also, Kaneko and Cornelius (1970) suggested that elevated serum cholesterol was indicative of hypothyroidism when used with other measures of thyroid function. The above findings particularly cholesterol levels, in conjunction with significantly ($P<.05$) increased thyroid weight/body weight and significantly ($P<.05$) lower T-4 values of pigs fed both C-RSM diets, indicate that a hypothyroid condition may have

existed in pigs fed the C-RSM diets. The cholesterol levels at this time may be particularly important in comparison to other times since Kaneko and Cornelius (1970) suggested that animals be fasted prior to bleeding.

Although slighlty greater amounts of tallow were used in the C-RSM than in the SBM diet, the same levels were used in the 00-RSM and in the C-RSM diets (Table 11). Swanson (1970) suggested that tallow could elevate cholesterol levels in pigs, but the fact that the cholesterol levels of the 00-RSM and SBM diets were not significantly different but both were significantly ($P<.05$) less than the C-RSM diet at 0-hours would indicate that tallow levels were not a main factor influencing cholesterol levels. This view is supported by the fact that chclesterol levels of pigs fed the C-RSM+SBM diet having 2.5% tallow were not significantly different from pigs fed the C-RSM diet.

At 4 hours post-feeding, 00-RSM and both diets with C-RSM showed increased levels of chclesterol ccmpared with the other diets. Alkaline phosphatase, although not significantly lower for either diet with C-RSM or the 00-RSM diet than for other two diets at this time, was numerically less.

At 8 hours, glucose levels in pigs fed the 00-RSM+SBM diet were considerably higher than other pigs ($P<.05$) but

were not significantly different from those fed the SBM diet. Uric acid was significantly ($P<.05$) depressed in pigs fed C-RSM+SBM diets compared with pigs fed the 00-RSM, 00-RSM+SBM and C-RSM diets.

At 12 hours glucose was significantly ($P<.05$) greater for pigs fed SBM and 00-RSM+SBM than other pigs. Albumin values were significantly higher for pigs fed these diets than was the case with 00-RSM or C-RSM diets ($P<.05$). LDH values were significantly ($P<.05$) higher for pigs fed the 00-RSM+SBM diet than for animals fed the 00-RSM or C-RSM diets. Bilirubin was significantly higher for pigs fed 00-RSM+SBM than pigs fed other diets. SGOT was also significantly ($P<.05$) greater for pigs fed 00-RSM+SBM and for pigs fed the C-RSM diets than pigs fed the other 3 diets.

Sex differences were apparent for a number of parameters: body weight at bleeding ($F<M$, $P<.05$), feed consumed at bleeding at 9 weeks ($F<M$, $P<.01$), phosphorus at 0-hours ($F<M$, $P<.05$), uric acid at 4 hours ($F<M$, $P<.05$).

Numerous significant replicate effects are apparent in Tables 16b-d. However, since these animals were all treated in the same manner and only one week separated the replicate bleedings, the cause of the significant replicate effects cannot be determined. These effects may demonstrate the

large amount of variability which was apparent in the results.

Significant differences between bleedings were evident, consequently further statistical analyses were made using bleeding times (initial, 0-hours, 4-hours, 8-hours and 12-hours) as a factor in the analysis of the data from each bleeding time. The overall data of bleeding times are presented in Table 16f.

A considerable number of interactions of bleeding times with various other parameters occurred in the overall analysis which were not evident when bleeding times were analyzed separately. These interactions are not consistent across treatments, sexes or replicates for the various parameters and will not be considered further. However, since the results in Table 16-f do show some large differences associated with time of bleeding, it is of value that these parameters should be considered in an overall analysis.

The highest value for serum calcium was found at the 0-hour bleeding and was lowest at 12-hours. Although these differences were significant ($P<.05$), the actual differences are small and within the normal range found by Kaneko and Cornelius (1970), Bowland (1975), Perrin (1975), Egbuiwe (1975), Aherne et al (1976) and Mia (1976) for pigs of the

weight range of the animals in the present experiment.

No significant differences between bleeding times were found for phosphorous and the range of the values are within normal limits shown by the above authors.

Glucose levels were significantly ($P<.05$) depressed at the 0-hour bleeding compared with other bleeding times and at the initial bleeding at 6 weeks glucose levels were significantly ($P<.05$) depressed compared to other values. Also, values at 4-hours after a meal were significantly ($P<.05$) higher than at other times. The minimum and maximum values noted above agree with common glucose metabolic theory that glucose levels increase during absorption of a meal as seen in the high value at 4-hours and decrease in the post-absorptive state as seen in the values at 0-hours (Lehninger, 1970).

Urea nitrogen was significantly ($P<.05$) higher at 4-hours and significantly ($P<.05$) lower at 0- and 12-hours than at other times. Values at 12 hours were significantly ($P<.05$) lower than at 0-hours but differences were not large. Orok and Bowland (1975) reported increase of plasma urea from 0-7 hours after feeding. The present results indicate that the peak blood urea concentration occurred at about 4-hours after feeding when measured at 9 weeks of age but Orok and Bowland (1975) found that much individual

animal variation occurred in the time of peak urea production. Considerable variation also occurred in the present study. In Tables 16b-e it appeared that urea level of the pigs fed 00-RSM+SBM was higher than values for pigs on other diets but differences for urea nitrogen were not significant at any bleeding time.

Uric acid was significantly ($P<.05$) higher at the initial bleeding at 6 weeks than any of the bleedings at 9 weeks. The initial value is markedly higher than those reported by Bowland (1975) and were found consistently in the data at 6 weeks. The values for serum uric acid reported by Bowland (1975) for combined 3 and 9 week samplings are similar to the results of the present study at 9 weeks.

Cholesterol increased significantly ($P<.05$) with age from 6 to 9 weeks, but values within the same day at 9 weeks were generally similar, although significantly ($P<.05$) less at 8 hours than at 0-hours following an overnight fast. As was noted in the analyses of the treatment effects at each time, pigs fed both diets containing C-RSM showed cholesterol levels that were significantly ($P<.05$) higher for pigs fed C-RSM compared to animals fed SBM or 00-RSM+SBM at the 0 and 4-hour bleedings but not at the 8 and 12-hour bleeding. Cholesterol levels of pigs fed the 00-RSM diet were generally intermediate between the above diets. Also

at 8 and 12 hours no consistent trends in serum cholesterol levels were noted. Interpretation of these data is difficult since treatment effects were not consistent but in general are within the ranges suggested by the data of Bowland (1975) and Aherne et al (1976). Diets with high and low oil contents were included in both of these reports and show that serum cholesterol was significantly ($P<.05$) higher in pigs fed high fat compared with low fat diets. Bowland (1975) found that 2% RS oil added to an SBM diet caused significant ($P<.05$) elevation in cholesterol in pigs. Swenson (1970) indicated in a review of the literature that large amounts of tallow could elevate serum cholesterol but no evidence could be found to indicate whether the tallow levels in these diets would likely cause any difference in serum cholesterol. Research on effects of cholesterol apparently involve wider differences in fat than these studies. In the present study fat levels were slightly higher in the C-RSM diet than C-RSM+SBM diet (Table 11). However, the same levels of fat were included in the 00-RSM as in C-RSM diets but cholesterol levels of pigs fed the former diet were not significantly different from pigs fed the SBM diet at the initial 0, 8 or 12 hour bleedings but were significantly ($P<.05$) different at 4 hours after bleeding. These results while not completely consistent, do indicate that the elevated serum cholesterol in pigs fed the C-RSM diet was likely a reflection of a reduction in thyroid

function and not due to the small differences in tallow in the diets in this study.

Total protein and albumin increased significantly ($P<.05$) from 6 to 9 weeks. Values for total protein were highest ($P<.05$) at 0-hours but albumin values were not significantly different at any bleeding time at 9 weeks.

Bilirubin showed opposite trends to glucose and urea nitrogen and was highest ($P<.05$) at 12-hours and lowest at 4-hours after feeding. Bilirubin was significantly lower at 4 hours than at 0-hours. This may reflect the secretion of bile during digestion. These values for bilirubin appear higher than those reported by Bowland (1975).

Alkaline phosphatase levels at the initial and at the 8- and the 12-hour bleedings were significantly ($P<.05$) less than at 0-hours. The findings at 0- and 12-hours are somewhat contradictory in that both represent periods of fasting and would be expected to show similar trends. Results of alkaline phosphatase determinations must be considered in light of the responses to treatments as were found for cholesterol, i.e. decreased alkaline phosphatase levels often found in hypothyroidism. Alkaline phosphatase, is, however, a very non-specific enzyme (Lehninger, 1970) which can be affected by many factors.

LDH and SGOT showed similar patterns of response to

alkaline phosphatase with values at 12-hours significantly ($P<.05$) greater than initial, 0- and 4-hour bleedings. The marked depression of SGOT at 0-hours is unusual in comparison with other values but still within the range indicated as normal by the work of Bowland (1975). The results at 12-hours post-prandial are nearly double those of Bowland (1975), Perrin (1975), Egbuiwe (1975) and Aherne (1976). Differences between treatments were significant ($P<.05$) only at 12-hours for LDH and SGOT when analyses of treatment effects were made at each bleeding time. These high values may be related to the high reading at 12-hours on an overall basis.

With the exception of bilirubin at 12-hours, the results obtained lie within the normal ranges determined by other workers.

The usefulness of these tests has been well established as diagnostic tools in human and veterinary clinical medicine (Van Kampan et al, 1972; Mia, 1976). As such, it is possible to conclude that no major myophathies or other degenerative conditions occurred during this trial.

Summary

The live animal performance in this experiment approximated the results in Part 1 of this thesis with the

exception of the 00-RSM+SBM diet. The depression of ADG and F/G for this treatment was not typical of performance of pigs on this type of diet. Results in Part 1 were much better for the 00-RSM+SBM diet than in the present experiment, and are also similar to findings of other workers.

ADG of pigs fed 00-RSM diets was significantly ($P<.05$) better than pigs fed C-RSM but significantly ($P<.05$) less than pigs fed SBM. ADF and F/G were also markedly depressed in pigs fed C-RSM, but differences were not significant, most likely an effect of the large variation of animals within treatments. Partial replacement of SBM by C-RSM resulted in a rate of growth intermediate between SBM and 00-RSM diets.

No significant differences due to treatments were found in the present study for DE, ME, DN coefficients nor for DE, ME or DN/kg of diet. However, results tended to be slightly better for the SBM diet than for any of the RSM diets but differences were not significant.

Fat and protein estimates of carcass liver and muscle were not influenced by dietary treatments to any great extent. However, protein content on a dry, defatted basis of livers of pigs fed the C-RSM diet was significantly ($P<.05$) less than that of pigs fed other diets.

Thyroid weights at 10 weeks of age showed that enlargement of the thyrcid occurred in pigs fed both diets containing C-RSM. Also, significantly ($P<.05$) lower T-4 levels were found in the serum of pigs fed those diets compared with the SBM and 00-RSM+SBM diets, but were still within the euthyroid range found by cther workers. It is then possible to conclude that C-RSM caused thyroid hypertrophy, but because the T-4 values fell within the euthyroid range of other workers, and serum cholesterol, glucose and alkaline phosphate were not changed consistently, it cannot be determined in this study whether or not a hypothyroid condition definitely existed. The possibility of a hypothyroid condition was probable for pigs fed C-RSM as the sole source of protein considering the severe depression of live animal performance for these pigs. These findings do not invalidate the general recommendations for feeding RSM to pigs because levels of C-RSM used (11.4-28.3%) were much higher than currently recommended levels of 5% RSM in the diet.

The analyses of serum constituents indicate that no gross myopathies or cther degenerative conditicns occurred.

The most important finding of this experiment was that the thyroid response of pigs fed the 00-RSM diet was markedly improved ccmpared with pigs fed the C-RSM diet.

Also, the hypertrophy which occurred with pigs fed both of the C-RSM diets did not occur to the same extent in pigs fed the 00-RSM diet. This is of particular importance considering the very high levels of 00-RSM which were fed. It can therefore be concluded that the residual levels of glucosinolates in Tower RSM should not be a barrier to increased utilization of this protein source for starting, growing and finishing pigs.

PART 3. EFFECTS OF DOUBLE-LOW RAPESEED MEAL ON GROWTH, APPARENT DIGESTIBILITY, CARCASS CHARACTERISTICS AND THYROID WEIGHT OF RATS

Introduction

Recent research has indicated that low glucosinolate RSM is of considerably higher nutritional value than high glucosinolate RSM. Bell et al (1972) found that no significant differences in feed consumption, body weight gain or feed efficiency were observed in rats fed diets containing either Bronowski RSM or casein as protein sources. A high glucosinolate RSM produced markedly inferior performance. Josefsson and Munk (1973) and Josefsson (1974) reported that no depression occurred in feed intake or body weight gain of mice fed diets containing RSM with less than 1 mg/g of total glucosinclates. Also, the growth response curve was inversely correlated with glucosinolate content.

Little information is available on the nutritive value of 00-RSM for rats. However, Seoane and Gorrill (1975) feeding diets with semi purified energy sources containing rapeseed flour and rapeseed oil from Tower rapeseed found that feed intake and body weight gain was significantly ($P<.05$) less for the rats fed Tower rapeseed flour than for rats fed soybean flour and corn oil. FCE however was

significantly (P<.05) better for rapeseed flour than soybean flour. Also energy and protein digestibilities were significantly (P<.05) improved for diets containing rapeseed flour compared with rats fed diets with soybean flour.

The objective of the present study was to assess the nutritive value of 00-RSM as a source of protein using weanling rats as the test species.

Experimental

Animals and diets

Fifty weanling rats of the Sprague Dawley strain at the Department of Animal Science, The University of Alberta, were fed the 5 diets used in the starting phase of the pig experiment in Part 1 of this thesis (Table 17). Diets were formulated to be isonitrogenous and isocaloric with a protein/calorie ratio (mg protein/kcal gross energy) of 42.6-44.5. NAS-NRC (1972) suggests that a protein/calorie ratio of 33 is adequate.

The experimental period was 4 weeks, from 3-7 weeks of age. A total of 20 females, 4 on each diet and 30 males, 6 on each diet, were maintained in individual cages in 2 batteries in the same temperature and humidity controlled room (22 C, 45% R.H.). Feed and water were available *ad libitum*.

Table 17. Formulation of diets (percentage basis - as fed)

Treatment no.	1	2	3	4	5
Protein source	SBM≠	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM
Ingredients					
Wheat	56.3	47.2	51.7	40.7	48.8
Barley	20.0	20.0	20.0	20.0	20.0
Soybean meal (48% C P)	17.7	0	9.4	0	10.0
OO-Rapeseed meal (38% C P)	0	25.3	11.9	0	0
C-Rapeseed meal (33% C P)	0	0	0	31.3	14.1
Animal tallow	1.5	3.0	2.5	3.5	2.6
Iodized salt	0.5	0.5	0.5	0.5	0.5
Limestone (ground)	1.0	1.0	1.0	1.0	1.0
Calcium phosphate	1.5	1.5	1.5	1.5	1.5
Mineral-vitamin premix	1.5	1.5	1.5	1.5	1.5
Composition-determined					
Dry matter %	90.9	90.5	91.9	92.3	92.5
Crude protein %	17.7	17.8	18.0	17.9	18.1
Gross energy kcal /kg	3987	4175	4030	4051	4018
Crude fibre %	4.1	6.2	5.0	7.4	5.7
Calcium %	0.93	1.04	0.98	1.11	0.99
Phosphorus %	0.75	0.87	0.78	0.97	0.89
Oxazolidinethione mg /g	0	0.3	0.1	0.5	0.3
Isothiocyanates mg /g	0.	0	0	0.8	0.3
Total glucosinolates mg /g	0.	0.3	0.1	1.3	0.6

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

• As in starter diets - Part 1.

Males averaged 63.5 g at allottment and females 58.8 g; this difference was statistically significant ($P<.05$). Body weight and feed consumption were determined weekly.

Digestibility studies

A digestion trial was conducted from days 11-14 with 3 male and 3 female rats in each treatment in one battery of cages. Feed consumption was determined daily during the digestibility study, feces were also collected daily and stored at 4 C until the end of the collection period, dried at 105 C for 2 hours and then ground in a laboratory mill. Digestibility coefficients were determined by the total collection method. Digestibility of energy and nitrogen was determined by the method of Sibbald et al (1957).

Apparent digestibility of amino acids of feed and feces was made using a Type 5AH amino acid analyzer[1] following the method outlined by Orck (1973).

Carcass analysis

At the end of the 4 week feeding period all males and 2 females in each treatment were weighed and then killed using chloroform. The remaining females were kept for other studies. Thyroids of rats that were killed were removed and weighed. Digestive tracts were removed, freed of ingesta

[1]Japan Electron Optics Co. Ltd., Tokyo, Japan.

and returned to the abdominal cavity. The weight of individual ingesta - free carcass was recorded as empty body weight. Each carcass was then oven dried at 60 C for 5 days until weight loss stabilized at about 1 g per day. After equilibrium to atmospheric conditions, weights were recorded as air-dry body weight.

The entire dried rat carcass was then dissolved by refluxing in 6N-HCl following the method outlined by Olomu (1974). The amount of acid used for digestion was based on 4 ml of acid per gram of dried carcass weight. The digesta of rat carcasses was made up to a standard volume of 500 ml by addition of distilled water.

Analyses of carcass dry matter, fat and Kjeldahl nitrogen were made according to standard A.O.A.C. (1970) methods using a 5 ml sample. Initial results indicated that it was necessary to heat the carcass digesta for a short time under a hot water tap and to stir using a magnetic mixer while sampling. This procedure resulted in uniform dispersion of fat which otherwise tended to collect at the top of the digesta.

Statistical methods

Analyses of variance (ANOVA) of the data were computed using the method of unweighted means outlined by Bancroft (1968). This procedure was necessary since preliminary

analyses indicated that significant differences occurred between the two batteries used to house the animals. This effect is identified as Location in the tables and may have been caused by frequent handling of the animals during the digestibility trial. However the effects should have been consistent across treatments and should not have influenced the results on any one treatment. Since 3 females and 3 males in each treatment were used in the digestibility studies, a total of 30 rats were housed in Location 1 and 20 in Location 2. Also, two females in each treatment used in the digestibility trial were retained at the completion of the study, therefore unequal representation of the sexes occurred in the carcass studies. Calculation of the adjustment required for the error mean square was outlined in Part 2 of this thesis.

Treatment means were compared using Duncan's Multiple Range Test (Steel and Torrie, 1960) which was preceded by a significant F test (Waldo, 1970). A probability of 0.05 was selected as the point of significance between means. The sources of variation were 5 diets and 2 sexes. All factors were tested against the adjusted error mean square as outlined by Bancroft (1968).

All sources of variation except location, replicate and animals were considered as fixed. Notations used to indicate level of significance are *(P<.05), **(P<.01),

***(P<.01). Means not significantly different bear the same superscript or no superscript.

Results and Discussion

The results will be considered in the order of live animal performance, digestibility of diets, carcass composition and thyroid weights.

Live animal performance

Body weight after 4 weeks on the experimental diets shows that rats fed SBM and 00-RSM+SBM weighed significantly (P<.05) more than rats fed the 00-RSM diet or the 2 diets containing C-RSM (Table 18). The same significant (P<.05) trend was found for feed consumption (FC) as for body weight. Body weight gain (BWG) and FC of rats fed 00-RSM was significantly (P<.05) less than rats fed SBM or 00-RSM+SBM diets. Rats fed both diets containing C-RSM gained significantly (P<.05) less than rats fed other diets. FC, BWG and 4-week weight of rats fed the C-RSM diet was significantly (P<.05) less than that of rats fed all other diets. Also, rats fed C-RSM required more feed per unit of gain (P<.05) than other rats. F/G of rats receiving half of the protein supplement from C-RSM was not significantly different from rats receiving 00-RSM but was significantly (P<.05) inferior to rats fed SBM and 00-RSM+SBM.

Table 18. Influence of diets and sex on food consumption, body weight gain and feed: gain ratio (4 weeks) in rats

Treatment no.	Protein source	Number of animals	Starting wt. g	4-week wt. g	Food consumption g	Body wt. gain g	Feed/gain
1	SBM[1]	10	61.5	192.7^{a}	446.2^{a}	131.2^{a}	3.50^{c}
2	OO-RSM	10	60.6	174.4^{b}	413.2^{b}	113.8^{b}	3.76^{bc}
3	OO-RSM+SBM	10	63.5	191.4^{a}	434.2^{a}	127.9^{a}	3.51^{c}
4	C-RSM	10	60.3	150.7^{d}	366.2^{d}	90.4^{d}	4.23^{a}
5	C-RSM+SBM	10	59.7	162.9^{c}	391.7^{c}	103.2^{c}	3.95^{b}
Sex							
F			58.8	147.9	374.8	89.1	3.31
M			63.5	201.0***	445.8***	137.5***	4.27***
Location							
1			60.6	169.6*	416.4	109.0**	4.0
2			61.7	179.3	404.2	117.6	3.6
Grand mean			61.1	174.4	410.3	113.3	3.8
S E M[+]			1.15	3.25	5.92	2.72	0.09

[1] SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

[+] SEM= Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at $P<.05$.

These findings in the main reflected the results of the pig studies except that rats appeared relatively more affected by the medium-high glucosinolate RSM used as the source of C-RSM in this study than did pigs. This was evidenced by the fact that in this present work FC, BWG and F/G of rats fed C-RSM+SBM were significantly ($P<.05$) inferior to rats fed 00-RSM. These differences were not found in the pig experiment. Hussar and Bowland (1959) found that BWG and F/G were depressed for rats fed 10% of a high glucosinolate *B. napus* RSM and that growth of pigs was also depressed by 10% but not by 2% RSM. Orck et al (1975) found that rats were affected to a greater extent by Span RSM than were pigs, as in the present study.

The present work was not entirely consistent with the reports of Josefsson and Munk (1973) which showed that diets containing RSM and having less than 1 mg/g of glucosinolate in the diet did not result in reduction in FC, gain or F/G for mice. In the present experiment, consistent reduction in performance was observed in rats fed the C-RSM+SBM diet containing 0.6 mg/g of total glucosinolates (Table 17). The RSM used in the C-RSM diets contained considerable quantities of ITC as shown in Table 4, whereas 00-RSM had very little. Thus, the combination of the levels of ITC and OZT present in the C-RSM used in this study appear to have affected growth at a level of 0.6 mg/g of diet. The results

suggest a continuous improvement in overall performance as glucosinolate level of the diets decreased. In Table 17 a ranking of the diets according to glucosinolate level indicates: C-RSM>C-RSM+SBM>00-RSM>(00-RSM+SBM=SBM). Inverse ranking was observed for performance. The results of the present trial indicate that growth response of rats fed RSM may show a continuous improvement as glucosinolate levels decrease, whereas for pigs, levels of 0.6 mg/g of diet resulted in performance similar to 00-RSM diets containing 0.3 mg/g of total glucosinolates. The results noted above for rats and pigs compared to mice in the work of Josefsson and Munk (1973) may be true species differences and indicate that caution is required in extrapolating growth responses to glucosinolate levels from one species of test animal to other species. The data of Bell et al (1972) support the view of a greater depression of growth in rats than mice to a variety of glucosinolates, as indicated by greater number of significant differences and relatively inferior performance of rats fed high glucosinolate B. napus, yellow Sarson, Oriental mustard or hydroxynitriles compared with mice.

Typical sex differences for rats were found with males significantly ($P<.001$) superior to females for all parameters of performance considered. Newell (1973) and Orok et al (1975) obtained similar results.

Certain significant location effects were found. Rats in the battery of cages used for the digestibility trial (Location 1) weighed significantly ($P<.05$) less after 4 weeks on trial and gained significantly ($P<.05$) less than rats in the other battery. F/G tended to be inferior for the rats located in the battery used for digestibility studies. Also, feed intake appeared greater for rats maintained in the digestibility battery although differences were not statistically significant for the last two parameters.

Digestibility of diets

Apparent digestibility coefficients for energy and nitrogen of the SBM and C-RSM+SBM diets were significantly ($P<.05$) greater than for the C-RSM diet (Table 19). DE and DN of the 00-RSM and 00-RSM+SBM diets were intermediate between the C-RSM and C-RSM+SBM and SBM diets but these differences were not significant.

DE/kg of diet showed that the DE of the C-RSM+SBM diets was significantly ($P<.05$) higher than for all other diets except 00-RSM while the other 3 diets were not different from each other. Significant differences ($P<.05$) were found for estimates of DN/kg of diet with higher ($P<.05$) estimates for C-RSM+SBM than the other 3 diets with RSM, but not significantly different between the SBM and C-RSM+SBM diets.

Table 19. Apparent digestibility of energy, nitrogen and amino acids in rats

Treatment no.	1	2	3	4	5	Sex		Grand	
Protein source	SBM	OO-RSM	OO-RSM+SBM	C-RSM	C-RSM+SBM	F	M	mean	SEM+
Number of animals	6	6	6	6	6				
Digestible energy %	82.6^{ab}	79.9^{bc}	80.1^{bc}	79.0^{c}	84.1^{a}	81.0	81.2	81.1	0.99
Digestible nitrogen %	82.5^{a}	79.5^{ab}	78.7^{b}	79.1^{b}	82.5^{a}	80.3	80.6	80.5	1.02
DE/kg diet kcal	3293^{b}	3335^{ab}	3252^{b}	3231^{b}	3437^{a}	3306	3313	3310	40.35
DN/kg diet g	23.3^{ab}	22.3^{c}	22.4^{bc}	22.7^{bc}	23.6^{a}	22.8	22.9	22.9	0.28
Amino acids %									
Essential									
Arginine	88.3	87.3^{ab}	85.7$_{b}$	85.9^{ab}	87.9	87.7	8 .8	87.2	1.26
Histidine	85.2^{ab}	85.5^{ab}	83.0^{b}	84.9^{ab}	87.3^{a}	85.1	85.3	85.2	0.87
Isoleucine	82.2^{a}	80.0^{ab}	78.1^{b}	78.2^{b}	82.3^{a}	80.1	80.2	80.2	1.02
Leucine	84.3	84.0	86.4$_{b}$	86.4^{ab}	85.2	85.2	85.4	85.3	0.83
Lysine	79.3^{a}	77.0^{ab}	74.5^{b}	77.4^{ab}	80.9^{a}	77.8	77.8	77.8	1.25
Methionine	75.3	78.0	73.7$_{b}$	77.2	79.1	76.5	76.8	76.6	1.42
Phenylalanine	81.5^{a}	78.9^{ab}	76.7$_{b}$	75.9^{b}	82.5^{a}	78.7	79.6	79.2	1.39
Threonine	79.2^{a}	77.2^{ab}	75.0^{b}	76.5^{ab}	80.0^{a}	77.4	77.8	77.6	1.15
Valine	81.7	80.5	78.3	79.1	82.5	80.3	80.6	80.4	1.03
Non-essential									
Alanine	76.7	77.3	73.4	75.6	78.5	76.3	76.3	76.3	1.22
Aspartic acid	81.4^{bc}	76.8	77.1	77.7	81.2	79.5	78.2	78.8	2.08
Cystine	93.2^{bc}	93.5^{bc}	91.8^{c}	94.7^{ab}	96.2^{a}	93.7	94.0	93.9	0.75
Glutamic acid	90.7^{a}	90.2^{ab}	88.8^{b}	89.0^{b}	91.0^{a}	89.9	90.0	89.9	0.51
Glycine	80.7	80.4$_{b}$	78.0$_{b}$	78.7$_{b}$	81.8	79.7	80.1	79.9	1.00
Proline	89.5^{a}	86.1^{b}	86.4^{b}	85.6^{b}	89.6^{a}	87.2	87.7	87.5	0.60
Serine	84.7^{a}	81.5^{b}	80.5^{b}	81.0^{b}	85.1^{a}	82.5	82.6	82.5	0.86
Tyrosine	78.3^{a}	75.4^{b}	74.0^{b}	71.6^{b}	78.0^{a}	75.4	75.5	75.5	1.28
Recovery of amino acids	81.0^{a}	73.7^{c}	77.5^{b}	74.6^{bc}	77.1^{b}	76.6	76.9	76.8	1.08

SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

+ SEM= Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at P<.05.

Lower DN values were found for 00-RSM than for the SBM or C-RSM+SBM diets ($P<.05$). Pigs also showed reduced digestibilities on diets in which either RSM completely replaced SBM. Hussar and Bowland (1959b) found that digestibility of energy and nitrogen as well as DE and DN/kg of diet was significantly ($P<.01$) depressed in rats fed diets containing 10% RSM of B. napus origin compared to controls fed SBM diets. In the same report of Hussar and Bowland, a definite but non-significant trend in pigs was also noted for lowered digestibility of diets by animals fed 10% RSM in the diet compared with pigs fed SBM. Bowland and Standish (1966) found no depression of digestibility of energy or protein in rats fed RSM of B. campestris origin when RSM comprised 15% of the diets. Glucosinolate levels in this report were not stated. Thus, it appears that the effect of RSM on coefficients of digestibility are variable but in the main, it is apparent from the present work that very high levels of RSM may cause a reduction in digestibility of energy and nitrogen in rats as well as in pigs.

Amino acids

Significant ($P<.05$) differences were found for apparent digestibilities of histidine, isoleucine, lysine, phenylalanine, threoninine, cystine, glutamic acid, proline, serine and tyrosine (Table 19). Digestibility of the above

amino acids in the C-RSM+SBM and SBM diets, with the exception of histidine and cystine, was significantly ($P<.05$) greater than the 00-RSM+SBM diet. The 00-RSM and C-RSM diets tended to have intermediate digestibilities, but were not significantly better than the 00-RSM+SBM diet for any of the above amino acids. Recovery of amino acids as a percentage of protein was significantly ($P<.05$) better for the SBM and significantly ($P<.05$) lower for the 00-RSM diet than for the 00-RSM+SBM or the C-RSM diet. Lowest digestibilities of amino acids across all the diets occurred for lysine, methionine and threonine. These are the amino acids most likely to be deficient in diets based on small grains and SBM or RSM (Rerat, 1972; Ivan, 1974; Aw-Yong and Beames, 1975). The same amino acids were also found to have the lowest apparent digestibilities in the pig trial except that lysine was significantly lower in the 00-RSM+SBM diet than in the SBM and C-RSM+SBM diets for rats. It is not possible to conclude from the present study that a problem of availability occurred for these amino acids within the different diets. A ranking of the digestibilities of all the amino acids across diets shows that the same relative differences occurred across all diets. Similar results were observed in the pig experiment.

No sex differences in any parameters of digestibility were found in the present study. This work is in agreement

with Bowland and Standish (1966) but Hussar and Bowland (1959b) found that digestibility of diets containing RSM was lower in female than male rats.

The overall trend of the digestibility of amino acids is that lower apparent digestibility was found in the 00-RSM, 00-RSM+SBM and in the C-RSM diets than in the SBM or C-RSM+SBM diets. These findings are not reflected in the performance data. BWG of rats fed diets containing 00-RSM was significantly ($P<.05$) better than either C-RSM diet. The relatively high digestibility of amino acids in rats fed the C-RSM+SBM diet and low digestibility in the 00-RSM+SBM diet is puzzling in that this effect was not reflected in performance of the rats, whereas the amino acid digestibilities were reflected in the perfcrmance of the pigs. The opposite situation existed for 00-RSM+SBM with low digestibility but high performance in rats, and high digestibility and high perfcrmance in pigs. Since digestibility trials by necessity are conducted over a short period of time relative to the entire experimental period, the possiblity exists that the results of digestibility studies may not agree with overall performance for the whole experimental period (Bowland, 1972, 1975).

The most important implication of this digestibility work is that the digestibility of amino acids is directly related to digestion of the entire diet. This is evidenced

by the fact that all estimates of energy and nitrogen digestibility show the same trends as seen in amino acid digestibilities (Table 19) including the high estimates for the C-RSM+SBM diet. In the pig experiment in Part 1 of this report, apparent digestibility of amino acids also closely approximated digestibility of energy and nitrogen. Sarwar et al (1975) suggested that lysine availability was lower in RSM than SBM for rats but this finding could not be evaluated in this present study. Later work by these authors using 00-RSM for pigs did not show reduced availability of lysine. A major difference between pigs and rats in the present digestibility study was that the low digestibility of the 00-RSM+SBM diet with rats was not reflected in low performance. Growth of rats fed 00-RSM+SBM was equivalent to that of rats fed the SBM diet. In pigs, both digestibility and performance on the 00-RSM+SBM diet were uniformly high and equivalent to pigs fed SBM diets.

The main point of the digestibility work with rats is that the findings with pigs of a reduction of digestibility with complete substitution of SBM with very high levels of RSM are confirmed. Both species showed a reduced digestibility of diets with complete substitution of SBM by 00-RSM or C-RSM. Although this depression of digestibility was not large it may account for the moderate reductions of F/G observed in pigs and rats fed 00-RSM compared with SBM

diets. The moderate depression of digestibility of C-RSM diets cannot account for the severe depression in performance which was attributed to high glucosinolate levels.

Carcass studies

As was mentioned in Part 2, chemical analyses of animal carcass tissues are often carried out in poultry studies in RSM work (Olomu, 1974) and also in rat studies (Sarwar et al, 1975). These analyses give some indications of effects of RSM on carcass characteristics as are obtained with market pigs.

Final weight, empty body weight and dry body weight were significantly ($P<.05$) greater for rats fed the SBM diets than rats fed 00-RSM or either diet containing C-RSM. Weights of rats fed 00-RSM+SBM were intermediate between rats fed 00-RSM+SBM diets. Weights of rats fed 00-RSM were significantly ($P<.05$) greater than those fed C-RSM or C-RSM+SBM diets. The empty and the dry B.W. of rats fed the C-RSM+SBM diet were significantly ($P<.05$) greater than those fed C-RSM. These results are to be expected since they are based on live animal body weights which showed similar trends of differences.

No significant differences were found for dry matter or carcass protein estimates. Body fat estimates showed that

Table 20. Influence of diets and sex on rat carcass composition

Treatment no.	Protein source	Number of animals	Final wt. g	Empty BW g ‡	Dry BW g	DM (Dry BW/ empty BW)%	Fat (DM) %	Protein (DM) %	Protein (Dry + defatted) %
1	SBM ≠	8	200.3^{a}	184.0^{a}	64.9^{a}	35.0	22.5^{bc}	59.8	77.3
2	OO-RSM	8	182.3^{b}	168.4^{b}	57.6^{b}	34.3	26.1^{a}	58.1	78.5
3	OO-RSM+SBM	8	198.0^{ab}	181.6^{ab}	62.5^{ab}	34.5	25.5^{a}	58.9	79.2
4	C-RSM	8	149.3^{c}	135.2^{d}	44.1^{d}	32.6	20.5^{c}	62.8	79.1
5	C-RSM+SBM	8	163.5^{c}	149.7^{c}	51.3^{c}	34.4	24.5^{ab}	59.1	78.4
Sex									
F			148.1	135.4	47.3	34.6	23.2	58.9	78.0
M			209.2***	192.1***	64.9***	33.6	24.5	60.6	78.9
Location									
1			168.0	157.2	53.3	33.8	24.5	60.2	76.6
2			189.3***	170.3	58.8*	34.5	26.1***	59.3	80.4
Grand Mean			178.7	163.8	56.1	34.2	23.8	59.8	78.5
S E M +			5.39	4.99	2.01	0.42	0.93	0.88	0.56

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid) C-RSM= commercial rapeseed meal.

+ SEM= Standard error of means.

a,b,c Means in the same row with the same letter or no letter are not significantly different at P<.05.

‡ BW= body weight; DM= dry matter.

rats fed both 00-RSM diets had significantly ($P<.05$) higher carcass fat than rats fed SBM or C-RSM. Rats fed the C-RSM diet were leanest but this may have been a reflection of the lighter live body weight of the rats on this treatment at the end of the trial.

The carcass fat analyses suggest that rats fed the 00-RSM diets retained a greater proportion of the feed consumed as fat compared with rats fed the SBM diet. This effect of greater fat in animals fed 00-RSM was not observed in pigs.

Sex differences were found only for carcass weights. Males weighed significantly ($P<.001$) more than females. This finding would be expected from the gain and 4-week weights observed for live animal performance. It is interesting that no differences in carcass fat were noted for sex in the rat studies whereas barrows in the pig study had greater backfat as reported in Part 1 of this thesis. No metabolic differences in digestibility or carcass characteristics due to sex were evident in the present work. This effect was also noted in the report of Orok and Bowland (1975).

Thyroid weights

No significant differences between treatments were found for thyroid weight (Table 21). The standard error of the means for these parameters is high indicating that

Table 21. Influence of diets, sex and body weight on weight of rat thyroids

Treatment no.	Protein source	Number of animals	Thyroid wt. mg	Thyroid wt./ final BW‡ mg /100g
1	SBM≠	8	11.9	6.1
2	OO-RSM	8	11.4	6.3
3	OO-RSM+SBM	8	11.0	5.8
4	C-RSM	8	9.6	6.3
5	C-RSM+SBM	8	9.7	6.1
Sex				
F			10.1	5.5
M			11.3	6.7***
Location				
1			10.6	6.4
2			10.8	5.9
Grand mean			10.7	6.1
S E M +			0.71	.32

≠ SBM= soybean meal; OO-RSM= rapeseed meal from Tower rapeseed (low glucosinolate, low erucic acid); C-RSM= commercial rapeseed meal.

+ SEM= Standard error of means.

‡ BW= body weight.

considerable variation occurred in thyroid weights. This factor may be a reflection of the difficulty in accurately removing and weighing all thyroid tissue in young rats due to the small size of the gland. However, a non-significant trend was apparent with glands of rats fed both diets containing C-RSM weighing slightly less than those of other rats. The body weight of rats fed C-RSM diets also was less than other rats, thus the difference in thyroid weights disappeared when expressed as a function of body weight. The latter findings, particularly, are not consistent with the results of the pig experiment in Part 2, where thyroid weight/body weight was significantly ($P<.05$) greater in pigs fed the C-RSM and C-RSM+SBM diets. It is possible that the large between-animal variation and relatively small number of animals in light of the large variation may have contributed to lack of significant differences in these results. Such effects have been found by Lo and Bell (1972) where diets containing rapeseed meal with up to 4 mg/g of glucosinolates failed to elicit significant differences in thyroid weight. In a previous trial Lo and Bell (1971b) had shown significantly ($P<.05$) increased thyroid weights of rats fed diets containing 2.6 mg/g of total glucosinolate. Thus, interpretation of thyroid weight data in rats as an indication of thyroid hypertrophy is uncertain.

Thyroid weight/body weight showed that thyroids of

females were significantly ($P<.001$) larger than males. Similar observations were reported by Hussar and Bowland (1959a), Manns and Bowland (1963), Bowland and Standish (1966), and Orok (1973). No interactions between sex and dietary treatments were noted in the present study nor in other reports. This indicates that RSM does not have a greater effect on thyroids of females than males.

GENERAL DISCUSSION OF PARTS 1-3

Pigs fed 00-RSM as a complete replacement for SBM as a protein supplement in diets based on barley and wheat gained faster ($P<.05$) and converted feed to body weight gain more efficiently ($P<.05$) than did pigs fed C-RSM in the starting, growing and finishing phases and in the overall experiment. ADF was significantly different in the starting phase with pigs fed SBM or 00-RSM+SBM consuming significantly ($P<.05$) more feed than pigs on the other 3 diets. In the finishing phase pigs fed both C-RSM diets consumed less ($P<.05$) than pigs fed the SBM diet. Pigs fed diets containing 00-RSM in substitution for SBM did not perform as well as those fed SBM, although the differences were not consistently significant. In the starter phase ADF of pigs fed 00-RSM was significantly ($P<.05$) less than pigs fed SBM diets but in the growing period ADG and F/G and in the finishing period ADG were significantly ($P<.05$) less for the pigs fed the 00-RSM diet. In all cases performance of pigs fed the 00-RSM diet was inferior to pigs fed the SBM diet.

Substitution of 00-RSM for 50 percent of the SBM resulted in live animal performance in pigs similar to, but in no case equal to or better than SBM. These findings were confirmed in the rat experiment and are confirmed by other reports.

Substitution of C-RSM for 50% of the SBM resulted in performance similar to pigs fed 00-RSM but complete substitution markedly depressed performance, particularly F/G in pigs. In rats, FC, BWG and F/G were markedly depressed by both C-RSM diets. These findings suggest that the rat is relatively more sensitive to medium-high levels of glucosinolate than is the pig but very high levels of commercial rapeseed caused a depression of FC in the early stages of growth as well as severe reductions in rate and efficiency of growth throughout the trials in rats and pigs.

Apparent digestibilities of energy, nitrogen and amino acids in diets with complete substitution of SBM by both sources of RSM were in some cases significantly reduced in pigs and in rats but in other cases the differences were not significant. A trend to lower digestibility of the 00-RSM and C-RSM diets was apparent. Lowest digestibility of amino acids was found for lysine, methionine and threonine, but the same relative depression in digestibility of these amino acids was noted across all diets. Therefore, it is not possible to conclude from the results of this study that availability of amino acids was a factor limiting growth in diets containing RSM. Apparent digestibility of amino acids was closely related to the overall digestibility of the diets including energy and nitrogen. It was suggested that the lower digestibility of both diets containing RSM as a

complete substitution for SBM may have been due to the high fibre levels as a result of high levels of inclusion of 00-RSM and C-RSM in these diets. In the case of the 00-RSM, the moderate depression of digestibility which did occur could, in conjunction with a reduced feed intake, have accounted for the moderate depression in performance of pigs and rats fed the 00-RSM diet. The high level of glucosinolates in commercial RSM were suggested to be the cause of the severe depression in growth of pigs fed the C-RSM diet.

No important effects of the diet on carcass composition were found in this study. Measurements on the carcasses of market pigs following slaughter and also on muscle and liver tissue and serum constituents of 10-week old pigs as well as entire rat carcasses indicated that normal protein and fat metabolism occurred. Differences in carcass composition which did occur could be attributed largely to carcass weight and sex.

Thyroid function was investigated by determining blood serum thyroid hormone levels as well as serum cholesterol, glucose and alkaline phosphatase as well as weight of thyroid glands in pigs and rats and assessing thyroid histology in pigs. T-3 and T-4 and P.B.I. levels of serum were found to be within the euthyroid range found by other workers although large mean differences for T-3 and T-4

occurred between the two time periods in one pig experiment. Serum T-4 levels were found to increase from 6 to 9 weeks of age but P.B.I. did not change in this interval. Significantly ($P<.05$) lower T-4 levels were found in pigs at 9 weeks of age which had been fed both diets containing C-RSM as well as 00-RSM in one case, compared with pigs fed other diets. Pigs fed both C-RSM diets also showed significant ($P<.05$) enlargement of thyroids relative to body weight as well as significantly ($P<.05$) elevated serum cholesterol and glucose and depressed alkaline phosphatase compared with pigs fed SBM. Although T-4 levels were within the euthyroid range of 2.7-10.5 ug/100 ml found by other workers, the performance of both pigs and rats was markedly depressed on diets with C-RSM as a complete substitution for SBM. Pigs fed C-RSM as a partial replacement for SBM grew at a rate similar to pigs fed 00-RSM whereas growth of rats was markedly depressed by this diet. Since in Part 2, thyroid weight/body weight of pigs fed the 00-RSM diets was greater than pigs fed the SBM diet and thyroxine levels in certain instances were not completely equivalent to those of pigs fed the SBM diet, it must be concluded that very high levels of 00-RSM may have had some effects on thyroid function. However, such effects appear to be minor and much less severe than the thyroid inhibitory effects of C-RSM.

As a result of the thyroid function assessment, it can

be suggested that hypothyroidism possibly occurred in animals fed the C-RSM diet. In the case of pigs fed C-RSM as a partial replacement for SBM, thyroid hypertrophy apparently occurred but growth rate was similar to pigs fed the 00-RSM diet. In the case of complete substitution of SBM by C-RSM, thyroid function in pigs was similar to pigs fed C-RSM+SBM diets but performance was markedly depressed. Performance of rats fed both C-RSM diets was inferior to rats on other diets. The results suggest that high levels of C-RSM not only caused thyrcid hypertrophy but also markedly depressed F/G which resulted in pocr performance. Rats appeared to be affected to a relatively greater extent than pigs particularly in terms of the perfcrmance characteristics.

These results do not negate current recommendations on the use of commercial RSM because much higher levels (7.2-33.1%) were used in the diets of pigs included in this study than are currently recommended.

The most important findings of this work are that high levels of Tower RSM (low glucosinolate, low erucic acid) used as a complete replacement for SBM resulted in a rate of growth which was markedly improved compared with RSM currently available commercially. Moderate reduction (8%) in the overall rate of gain occurred in pigs fed Tower RSM as a complete replacement for SBM when compared to SBM.

This effect was largely attributed to reduced digestibility and some reduction of feed intake of the diet resulting in less efficient conversion of feed into body weight gain. Reduced digestibility of the dietary energy, nitrogen and amino acids may have been associated with higher CF in diets containing RSM. Partial replacement of 50 percent of the SBM by Tower RSM resulted in no significant reduction of ADF, ADG and F/G.

It can therefore be concluded that the glucosinolates remaining in Tower RSM are not a major concern in the diets of starting, growing and finishing pigs and are not a barrier to increased usage of Tower RSM as a protein source for pigs. Levels up to 11 percent RSM from Tower RS in the diet or one-half of the supplemental protein should not result in any significant reduction in growth, feed intake or feed conversion efficiency. Lower fibre levels in RSM would be of benefit particularly for young starting pigs. It is also recommended that in breeding of rapeseed cultivars, lysine and methionine levels be maintained or increased.

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